Everything Has A History

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J.B.S. Haldane

Vigyan Prasar

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VIGYAN PRASAR

An Introduction

Vigyan Prasar (VP) was set up by the Department of Science and Technology, Government of India, as an autonomous registered Society in 1989 for taking up large-scale science popularisation tasks. Its broad objectives may be summarised as follows:

To undertake, aid, promote, guide and coordinate efforts in popularisation of science and inculcation of scientific temper among the people and to increase the knowledge, awareness and interest about science and technology among all segments of the society.

To provide and promote effective linkages on a continuing basis among various scientific institutions, agencies, educational and academic bodies, laboratories, museums, industry, trade and other organisations for effec-tive exchange and dissemination of S&T information.

To undertake development of materials — audio, visual, audio visual and printed — methods and modes of communication, so as to enable the masses to better understand, appreciate and comprehend abstract scientific principles and practices.

To organise research work, courses, workshops, seminars, symposia, training programmes, fairs, exhibitions, film-shows, popular discussions, street plays, quizzes, song-dance-dramas etc., in furtherance of the objectives of the Society.

After its establishment Vigyan Prasar remained dormant for a few years. Only in 1994 some activities could be taken up in right earnest. One among the first few programmes initiated by Vigyan

Prasar was the 'Ready-to-Print' Science Page project. The idea was to prepare a well laid-out newspaper-size page with one or two features and several smaller items on scientific and technological (S&T) developments taking place in India, appropriately supported with photographs, illustrations, graphics etc., and to supply it to newspapers to carry as it is. Initially, such pages in Hindi and English were planned for release once a month. Subsequently, a children's page, science pages in other major Indian languages and a feature packet service were also added. Today, these pages are being carried once or twice a month by more than 30 editions of some 20 newspapers spread all over the country. Infact, today Vigyan Prasar's are the largest circulated science pages in the country. The combined print order of all these newspapers exceeds 2.5 million copies. These pages have led to fresh demands for enhanced science coverage in other newspapers.

Vigyan Prasar's publications programme is gradually taking shape. A number of important series has been launched; some more are planned. The first major English publication brought out by Vigyan Prasar, viz., *"Memoirs of Ruchi Ram Sahni: Pioneer of Science Popularisation in Punjab,"* under its series on Pioneer Science Popularisers in Pre-Independence India. has generated positive awareness among science communicators and enthused researchers about the need to unearth other such personalities in other parts of the country. Already names of a number of individuals who did pioneering work in the field of science popularisation in pre-independence India have come to light.

Popular science classics written by Great Masters in the past, which have inspired generations of students of science, are no longer seen in the hands of our younger generation. This is not because these books have gone out of context, but because they are no longer available. Vigyan Prasar under its Popular Science Classics series intends to reprint these books and bring them out in low-priced

affordable editions so that more and more children can have them. Already two such classics (Michael Faraday's *Chemical History of a Candle* and C.V. Boys' *Soap Bubbles And the Forces Which Mould Them)* have been brought out and more are on the way.

Inspired by the focal theme for the National Science Day-1995, viz., 'Science for Health', Vigyan Prasar initiated a Health Series. Under it publications on all common diseases, along with possible management of their curative and preventive aspects would be brought out. The first three titles on *Sexually Transmitted Diseases, Asthma and Jaundice,* have already been released.

Under its series of Monographs on India's Scientific Heritage Vigyan Prasar intends to bring out publications on specific science and technology areas in which India's contributions have stood the test of time, as also have made an impact on modern-day science. The first monograph in the series *'The Rustless Wonder : A Study of the Iron Pillar at Delhi'* was released on 30 January 1997. The second volume *' Where Gods Come Alive : A Study of the South Indian Bronze Icons '* would be going to the press shortly.

The Total Solar Eclipse of October 24, 1995, provided Vigyan Prasar a rare opportunity to organise a country-wide awareness campaign, aimed at dispelling age-old myths and superstitious beliefs related to eclipses, and to develop among people an urge to learn about their known scientific aspects. Vigyan Prasar jointly with the National Council for Science and Technology Communication (NCSTC) organised a number of activities:

i. Telescope-making workshops for students and teachers.

ii. Development and production of books, a total solar eclipse chart and an activity kit for children.

iii. Production of several video films and their telecast.

Vigyan Prasar conceptualised and implemented a novel idea for ensuring that people did come out and watch the total solar eclipse. It circulated a total solar eclipse pledge. People in thousands from all corners of the country sent in signed pledges. Many individuals and voluntary agencies got these pledges translated into regional languages on their own and distributed the same in large numbers. All this led to a chain of activities throughout the country. The efforts made by VP, NCSTC and other agencies created a situation where millions of people came out and watched the spectacular event. This was a unique experience and made Vigyan Prasar's name a household word throughout the country.

Under its audio-visual programme, Vigyan Prasar developed a set of video films and several radio programmes on the occasion of the total solar eclipse of 24 October 1995. This event-based effort was enormously satisfying for the VP family and generated a very good response from the public at large.

Vigyan Prasar has recently begun building an Information System called VIPRIS — acronym for **VI**gyan **PR**asar **I**nformation **S**ystem — to meet a long-standing demand from different quarters, particularly the science communicators, to establish a repository of background data and information on various aspects of S&T which would be accessible easily. The computerised system would be built on a modular basis, and aim to meet the information needs of science communicators of all kinds.

At this stage, under VIPRIS, we have a fortnightly clippings service, an electronic bulletin board service (BBS), two pages daily on Doordarshan's teletext service and weekly science news on the radio. Several other products and services including training, development and production of CD-ROMs, generation of data bases on different subject areas etc., are being planned

The first phase of the database on " Environment & Safety Laws : Regulations & Guidence. Documents " has been completed. VP launched its Home-Page on the Internet on 12 September, 1996. An online electronic popular science magazine 'ComCom' , has been planned as part of the Home page. The other sections of the Homepage are, About Vigyan Prasar , Daily Weather Report, Sky map of the days/month links with other related homepage, S&T vacancies in India, News from S&T laboratories, S&T databases etc. It has provision for Hindi HTML and support for Web browsers / users to download the Hindi Plug-in and install it in their system. It has also a discussion forum with support to display and keep visitors' view.

Vigyan Prasar has also produced audio-cassette sets of the 108-part radio serial 'Manav Ka Vikas' (jointly produced by the NCSTC and All India Radio) in 18 Indian languages.

A number of video programme has also been produced. Recent ones among them have been on "Herbal petrol" and "Comets"(in connection with the coming of the comet "Hale-Bopp"). Several other programme are possibly under production.

This is not all. Vigyan Prasar does many other things. But for now this should suffice.

Narender K. Sehgal
Director
Vigyan Prasar

Glimpses of Life and Work of John Burdon Sanderson Haldane*

"I am a part of nature, and, like other natural objects, from a lightning flash to a mountain range, I shall last out my time and then finish. This prospect does not worry me, because some of my work will not die when I do so."

J.B.S. Haldane

To many, John Burdon Sanderson Haldane needs no introduction and perhaps 'no one can explain his writing better than himself.' However, our aim is to introduce Haldane's writings to younger people and a non-scientific audience and we feel that many of them may not be knowing who Haldane was and what he did. Many of the traits of Haldane's personality are truly inspiring and his concerns and views on the development of science and its relationship with society, the importance of the method of science, education, welfare of fellow human beings etc., are very much relevant even today. He spent last five years of his life in India and became an Indian citizen. Keeping this in view we have attempted to highlight some aspects of Haldane's life and work. For obvious reasons it cannot be a definitive and comprehensive account.

Haldane was a polymath in a real sense. As a scientist his best known contributions are in the mathematical theory of evolution. He is one of the founders of population genetics. However, he wrote as if he were equally at home in population genetics and astrophysics. In fact his knowledge of the latter was really amazing. Haldane was actually interested in almost all the sciences.

He was a man of massive contradictions. While in science Haldane was the most open minded of men but in politics he was dogmatism incarnate. He could be the rudest man as well as the kindest. He was thrifty and never wasted anything. He disliked formalities and

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* *Prepared by Subodh Mahanti*

always meant business. He had no liking for social visits and non-scientific conversations.

Family background and Education

J.B.S. Haldane was born in Oxford, England, on November 5, 1892. Haldane's family traces its ancestry to the mid-thirteenth century. His father John Scott Haldane (1860-1936) was a physiologist, noted for his investigations of human respiration. He established that the rate of breathing was regulated according to the concentrations of carbon dioxide in the blood. He also investigated the effects of high altitude deep sea pressure on respiration and improved mine safety by demonstrating toxic effects of carbon monoxide.

His mother Louisa Kathleen Haldane (nee Trotter) was involved in activities aimed at relieving the "human predicament". Haldane was very much influenced by his parents; particularly by his father. He once observed: "I owe my success very largely to my father". Haldane received his initial scientific training from his father whom he assisted from childhood in the latter's private laboratory. Thus he later observed, "I learned much of my science by apprenticeship, assisting my father from the age of eight onwards and my university degree is for classics, not for science"

About his childhood Haldane wrote:

"As a child I was not brought up in tenets of any religion, but in a household where science and philosophy took the place of faith. As a boy I had very free access to contemporary thought, so that I do not today find Einstein unintelligible, or Freud shocking. As a youth I fought through the war and learned to appreciate sides of human character with which the ordinary intellectual is not brought into contact. As a man I am a biologist, and see the world from an angle which gives me an unaccustomed perspective, but not, I think, a wholly misleading one.

"At school I deserted "classics", that is to say, the study of Latin and Greek, at the age of fourteen and studied chemistry, physics, history, and biology, with my father's full backing but to the annoyance of the headmaster, who said I was becoming "a mere smarterer."

Haldane had a great regard for literature. We are told that he was fond of Shakespeare (1564-1616); Dante (1265-1321); Sheley, (1797-1851); Keats (1795-1821); Rimbaud (1854-91) and Balzac (1799-1850). He also used to read Dostoevsky (1821-81) and Tolstoy (1828-1910). He was friendly with G.B. Shaw (1856-1950) and H. G. Wells (1866-1946). He could read eleven languages and make public speeches in three.

In 1911 he went to Oxford on a mathematics scholarship and took first-class honours in mathematical moderations. In his first year at Oxford, he also attended the final honours course in zoology. At a seminar for zoology students in 1911, Haldane announced his discovery (based on the analysis of the data published by others) of the first case of what is now called linkage between genes in vertebrates. However, his evidence was not adequate and he had to wait till 1916 to get it published.

Before he could obtain a formal scientific degree, he had to leave Oxford and join the British army in 1914, as the First World War (1914-18) broke. On returning to Oxford after the war, he was elected a Fellow of New College and started teaching physiology. Besides his teaching assignment he started working on physiology and genetics.

Contributions to Science

Haldane's major contributions to science were in three different fields, i.e. physiology, biochemistry and genetics.

He studied various aspects of human physiology, often acting as his own experimental animal. In fact Haldane is noted for his willingness to serve as "his own chief guinea pig". Haldane's 'work on regulation of blood alkalinity is basic textbook material'.

In 1922, on invitation from Frederick Gowland Hopkins (1861-1947), Haldane joined the Cambridge University as Reader in biochemistry. He spent 10 years there. At Cambridge he concentrated on the study of enzymes and using some elegant mathematics he calculated the rate at which enzyme reaction takes place. Haldane (in collaboration with G.E. Brigs) showed that enzyme reactions obey the laws of thermodynamics. On his contribution to biochemistry Haldane

wrote: "Perhaps my own most important discovery was that a substance, for which carbon monoxide competes with oxygen, now called cytochrome oxidase, was found in plant seedlings, moths and rats. The most remarkable thing about this discovery was that I was able to find out a good deal about a substance in the brain of moths without cutting them up or killing. However, my enunciation of some of the general laws of enzyme chemistry may have been more important."

Haldane is considered as one of the founders of population genetics. His main genetic discovery at Cambridge was the rule to determine the sex of the hybrid animal : "The rule that if one sex in a first generation of hybrids is rare, absent or sterile, then it is the heterogamatic sex". In 1933 Haldane left Cambridge for the University College of London where he was mostly preoccupied with human genetics. He prepared (1935) a provisional map of the X chromosome which showed the positions on it of the genes causing colour blindness, a particular skin disease and two varieties of eye peculiarity. His work on the mathematical theory of natural selection is a must for students of genetics and biology. In 1932, in his book, *The Causes of Evolution,* Haldane published the first estimate of a human-mutation rate. Another important contribution of Haldane to the field of genetics was his work for the *Journal of Genetics,* which he edited.

Haldane and A. I. Oparin independently suggested a plausible mechanism for the origin of life in an anaerobic pre-biotic world.

Perhaps the most important aspect of Haldane's contributions to science was that he was able to bring to new fields the equipments and concepts he had acquired in other disciplines.

In Haldane's own words his scientific contribution may be summarised as follows : "My scientific work has been varied. In the field of human physiology I am best known for my work on the effects of taking large amounts of ammonium chloride and ether salts. This has had some application in treating lead and radium poisoning. In the field of genetics I was the first to discover linkage in mammals, to map a human chromosome, and (with Penrose) to measure the mutation rate

of a human gene. I have also made some minor discoveries in mathematics".

Awards & Honours

Haldane was elected a Fellow of the Royal Society in 1932. The Royal Society awarded him its Darwin Medal in 1953 " in recognition of his initiation of the modern phase of study of the evolution of living population". The French Government gave him the Legion of Honour in 1937 and the Academia Nazionale dei Lincei gave him the *Feltrinelli Prize* (1961). The other awards he received were: *Weldon Memorial Prize* from Oxford University; the *Darwin Wallace Medal* of the Linnean Society; the *Huxley Memorial Medal* of the Anthropological Institute and *Kimbler Genetics Award* of the US National Academy of Sciences. He was President of the Genetical Society (1932-36).

An Outstanding Science Populariser

Haldane was an outstanding science populariser. His popular writing was remarkably lucid. He had the ability to present complicated concepts of science in a simple way without distorting their meaning. His articles, lectures and broadcasts made him one of the best known scientists in the world.

He stressed the social responsibilities of science. Haldane considered it an important duty of a scientist to render science intelligible to ordinary people. He wrote volumes of essays explaining science to the lay man.

To science communicators Haldane advised:

"You are not trying to show off; nor are you aiming at such accuracy that your readers will be able to carry out some operation. You want to interest or even excite them, but not to give them complete information. You must therefore know a very great deal more about your subject than you put on paper. Out of this you must choose the items which will make a coherent story...This does not mean that you must write for an audience of fools. It means that you must certainly be returning from the unfamiliar facts of science to those of everyday

experience...When you have done your article, give it to a friend, if possible a fairly ignorant one. Or put it away for six months and see if you still understand it yourself. You will probably find that some of the sentences which seemed simple when you wrote them, now appear very involved. Here are some hints on combing them out....Can you get in a full stop instead of a comma or a semi-colon? If so, get it in. It gives your reader a chance to draw his breath. Can you use an active verb instead of a passive verb or verbal noun?"

He believed that the non-scientific audience "... has a right to know what goes on inside the laboratories, for some of which it pays."

Views on Education

He was a great advocate of the concept of learning by doing. For example once he wrote: "A feeling for numbers can only be acquired by practice. What should the practice be? As an example I want our students to make a census of all the trees in the compounds of number 203 and 204 B. T. Road. They will come up against real difficulties. Is this a tree or bush? Is this one banana plant or a dozen? This is no harder than deciding what is a factory or a household. I estimate that there are rather under 100 betel-nut palms in the compound of No. 203. I may be wrong, I haven't counted them. But I want our boys and girls to get the feel of what a hundred trees look like, and constantly to be asked `How many?', `How often?', How powerful?' and so on."

He advised his students to highlight the relation between abstract scientific concepts and real-life experience, which he himself did throughout his life. Thus he noted: "You must constantly be returning from the unfamiliar facts of science to those of every day experiences."

Haldane's comments on the then existing educational system are still worth considering. He observed: " Our present educational system is unjust to children because the majority of them don't get a fair chance and practically none are taught the truth of science from a human point of view. Science teaching should begin, not with a

mythical body in rest or uniform motion, but with the human body. Mine did so begin at the age of 3."

Political and Social Outlook

J.B.S Haldane was very much concerned with human welfare. Being a liberal in his student days at Oxford, he moved towards left and finally formally joined the Communist Party in 1942. But before this, he wrote The *Marxist Philosophy and the Sciences* (1938) and a preface and notes (1940) for translation of Engles' *Dialectics of Nature* which had been left uncompleted in 1882. It seems Haldane was very much impressed by Engles' views. Thus he wrote, " Had his (Engles) remarks on Darwinism been greatly known, I for one would have been saved a certain amount of muddled thinking". He had become the Chairman of the editorial board of the *Daily Worker* for which he wrote more than 300 articles on scientific themes often mixed with political comments. He also wrote more than 100 articles in left-wing papers such as the *Reynolds News*. Haldane became socialist because he wanted to see his fellow men and women enjoying the advantages which he himself enjoyed. His social and political outlook was very much influenced by his rigidly quantitative approach, his immense knowledge of genetics, and his sense of duty. Haldane could not agree with the Communist Party's total lack of skepticism and moved away from it quietly.

For an ideal society Haldane said the following:

"The ideal society would enable every man and woman to make the best of their inborn possibilities. Hence it must have two characteristics. First, liberty, which would allow people to develop along their individual lines, and not attempt to force all into one mould, however admirable. Second, equality of opportunity which would mean that, as far as is humanly possible, every man and woman would be able to obtain the position in society for which they are best suited by nature."

Haldane was conscious of the fact that to give shape to his social and political ideas he must have the support from all sections of the society.

In India

In 1957 Haldane moved to India, ostensibly in protest against the Anglo-French invasion of Suez. His decision to move to India was also influenced by the country's facilities for research in genetics and biometry. He joined the Indian Statistical Institute (ISI), Calcutta, at the invitation of P. C. Mohalanobis. At ISI he gave great impetus to the theoretical and applied research by initiating several research projects on quantitative biology. He was also instrumental in formulating (jointly with P. C. Mahalonobis) the academic programmes for Bachelor of Statistics (Honours) course at the Institute.

On his association with the Indian Statistical Institute Haldane observed : "I owe a great deal to this institute but I undoubtedly owe most is the opportunity it has given me of making some important discoveries, namely, the discoveries of a number of younger men than myself, who, I think are in the great tradition of scientific research."

He resigned from the Indian Statistical Institute in 1961 and set up a research unit in his residence with the financial assistance from the Council of Scientific and Industrial Research and with the cooperation of his several colleagues. In 1962 he moved to Bhubaneshwar to set-up a Genetics and Biometry Laboratory.

Haldane had a deep appreciation of the Indian culture and he wrote extensively on its relations to modern science. He was deeply engrossed in Indian philosophy. He had a good knowledge of Sanskrit. In April 1961 he became an Indian citizen.

His important works*

Haldane wrote on varied subjects. He continued to write till he died in 1964. He wrote twenty-four books (including science fiction and

*A biblography of all Haldane's scientific work has been made by N.W.Pirie (in *Biographical Memoris of Fellows of the Royal Society*, London, 12, 1966.) and which has been reproduced in Ronald W.Clark, J.B.S.: *The Life*

stories for children) more than 400 scientific research papers and innumerable popular articles. On his writings Haldane wrote: "Besides scientific books I have written a number of popular works, including a book on children's stories. I consider that a scientist, if he can do, should help to render science intelligible to ordinary people and have done my best to popularise it". Some of his important works are:

Daedalus; or Science and the Future (1924); Callinicus: A Defense of Chemical warfare (1925); The Last Judgement (1927); Animal Biology (1927 with J.S. Huxley); Possible Worlds and other Essays (1927); The Origin of Life in Rationalist Annual (1929 pp 3-10); Science & Ethics (1928); Enzymes (1930); The Inequality of Man and Other Essays (1932), Science and Human Life (1933); Fact and Faith (1934); The Causes of Evolution (1933). Science and the Supernatural (1935 - with A Lunn); My Friend: Mr Leaky (1937 - for children); The Marxist Philosophy and the Sciences (1938); Heredity and Politics (1938); Science and You (1939); Science in Everyday Life (1940); Preface and Notes to Dialectics of Nature (F. Engels, translated and edited by C. Dutta, 1940); Science in Peace and War (1940); New Paths in Genetics (1941); Science Advances (1947); What is Life (1947).

Last will

He died on December 1, 1964. As per his will his body was sent to the Rangaraya Medical College, Kakinada. "My body has been used for both purposes during my lifetime", Haldane wrote in his will, "and after my death, whether I continue to exist or not, I shall have no further use for it, and desire that it shall be used by others. Its refrigeration, if this is possible, should be a first charge on my estate".

Some Sources on Haldane's Life and Works:

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Introduction

The world has seen few science popularisers of the calibre of J.B.S. Haldane. Most scientists write erudite research papers, whose technical jargon makes little sense to ordinary people. No wonder that very few scientists have succeeded in interpreting and communicating science to a layperson. Haldane was not only a brilliant scientist but also a great science writer. A pioneer biologist, biochemist and geneticist, he helped provide the mathematical foundation for Darwin's theory of natural selection. Haldane was a professed Marxist. As the chairman of the editorial board of the DAILY WORKER -- the mouthpiece of the Communist Party of Great Britain -- he wrote 300 brilliant articles on popular science for ordinary workers. He earnestly believed that every worker or craftsman, worthy of his profession, must understand the science & technology underlying his trade. This appreciation would make the job much more interesting. Many of these essays were later collated into books like EVERYTHING HAS A HISTORY and SCIENCE IN EVERYDAY LIFE. His book ON BEING THE RIGHT SIZE remains an outstanding piece of popular science literature.

Haldane had great respect for ordinary working people. He trained miners to search for fossils while digging coal. They were the best people to hunt for fossils anyway. And everytime a miner found a fossil he was rewarded by Haldane with a prize of 10£. Very soon there was a veritable museum of fossils collected by ordinary miners!

Arvind Gupta

EVERYTHING HAS A HISTORY

BY J.B.S. HALDANE

J.B.S. HALDANE WAS ON THE EDITORIAL BOARD OF 'THE DAILY WORKER'. JBS USED TO SAY THAT EVERY SELF RESPECTING WORKER SHOULD UNDERSTAND THE NATURE OF HIS/HER WORK & THE SCIENTIFIC PRINCIPLES UNDERLYING IT. CONSEQUENTLY, JBS HALDANE WROTE THESE SCIENCE ARTICLES FOR WORKERS. THE ARTICLES BEAR THE LUCID STYLE & CLARITY OF CONCEPTS.

I ASK FOR FOSSILS

In the last hundred years it has become constantly harder for ordinary workers to contribute to scientific research. The great physicist Faraday started off as a bookbinder's apprentice and went straight into research work. A bookbinders' apprentice wouldn't find it so easy to-day. But there is one important contribution to knowledge which can only be made by coal miners. That is the collection of fossil animals from the coal measures. This article is a call to miners to help in the work. Those who do so can not only contribute to science, they can earn good money.

Everyone knows that the coal seams consist of the remains of vegetation which grew in swamps. Very few bones or shells are preserved in the coal itself, because rotting vegetation produced acids which ate them away. But the newly-formed coal was often submerged under sand or mud, which hardened to sandstone or shale, to form the roof of the coal seam. In these rocks fossils are sometimes found.

Now shells, resembling those of modern mussels, cockles, scallops and snails, are fairly common in the coal measures. They have been used for dating the rocks. While they are quite interesting, I doubt if anyone will buy them. On the other hand the remains of vertebrate animals are of very great interest and some monetary value. By vertebrates are meant animals with backbones, including fish, amphibians, reptiles, birds and mammals. Any bones or teeth, and most scales, come from vertebrates.

So far only two classes of vertebrates have been found in the coal measures, namely fish and amphibians. The fish were not so very different from modern fish. The amphibians were mostly four-footed animals, rather like modern newts. But some of

them were much larger. The smallest were only about three inches long, the largest up to twelve feet, as big as modern crocodiles. Occasionally a complete skeleton is found, more often a skull or a few vertebrate from a backbone, most usually only single scales or fragments of bone. The fish are far commoner than the amphibians. Both these classes of animal are very interesting to the student of evolution for this reason. The ancestors of the amphibians were fish which developed legs in the Devonian period, before the coal measures were laid down. But the amphibians in the coal measures were much more like fish than are modern frogs or newts. And some of the fish of the coal measures were much more like those which gave rise to the amphibians than any modern fish. So by studying them we can learn something about the change by which the first four-legged animal arose.

"Is it not possible," a reader may ask, "that one might find the bones of some much more highly developed animal such as a bird, or something like a horse or a dog, in the coal measures?" The answer is that it is not impossible. But if such a fossil were found, it would disprove the theory of evolution. For biologists believe that they have found the fossil bones and teeth of a great many of the steps by which mammals and birds evolved from reptiles. And these are found in rocks laid down long after the coal seams. So such a discovery would be most surprising.

In spite of their interest, we know very little about British vertebrates from the coal measures. A few have been found in Scotland. Ninety per cent of the English ones come either from Newsham pit in Northumberland, which is now closed, or from the southern end of the North Staffordshire coalfield. The man who was mainly responsible for the collection at Newsham was T. Atthey, a grocer. He bought them from miners in return for credit at his shop, and sold them to museums and to palaeontologists, probably making a very good profit out of them. J. Ward, in Staffordshire, certainly collected himself, but also seems to have bought specimens from miners. Both these men lived in the

nineteenth century, and collected fossils over a period of about thirty years. During the present century nothing has been found but a few fish-bones.

The reason for the falling off is perhaps that nowadays there are fewer amateur fossil collectors than eighty years ago. The collection, and still more the preparation, of fossils is a highly skilled business. The amateur is less likely than he was to find anything fresh in most places. But this is not true of coalmines. To-day the coal miners are far better educated than their grandfathers, and they are just as likely to find something of real scientific interest.

Where should they look? The vast majority of vertebrate fossils occur in cannels, in cannel-like shales, or in nodules of ironstone imbedded in thick shales. They are most likely to be found in the roof of a coal seam, but they may be found elsewhere. So far as we know they may occur in any coalfield. The southern end of the North Staffordshire field is perhaps the most hopeful area. But fossils found there are likely to be of kinds already known, while those from other places will more probably be of hitherto unknown animals.

Unfortunately the fossils occur in small patches, perhaps where a pool containing a number of fish dried up, and their skeletons were buried under mud. Such an area is only worked for a short time. It is very unlikely that any particular reader of *Coal* will find any. But if ten thousand miners start keeping their eyes open, it is pretty sure that a dozen of them will find some fossils.

In order to start the ball rolling, I will offer £5 for the first fossil fish or part of a fish sent to me and £10 for the fist fossil amphibian or part of an amphibian.* If the find is worth more, that is to say if the British Museum or some other museum will give

* The £5 has been paid. Unfortunately the £10 has not.

more for it, I will hand over the price, and the same with any later finds. It is essential that the place of finding should be accurately stated (e.g. roof of the ---- coal seam, about ----- yards N.N.W. from the ----- shaft of the ---- pit. If the specimen is found among shale in a dump or on the surface, the name of the pit should be given, and any possible indication as to where the fossil probably came from. My address is :

Prof. J.B.S. Haldane, F.R.S
Dept. of Biometry
University College,
Gower Street, London, W.C.r.

I am not much of a Palæontologist myself, but I have some younger colleagues who are experts on fossils, and are out to help me. In fact the scheme is theirs, and not mine. I have also arranged with the editor of *Coal* to publish the names of the first finders, and of anyone who makes a notable find later on, unless they ask that their names should be kept back.

The value of a fossil is anything from about a shilling for a fish scale or tooth, up to several hundred pounds for the complete skeleton of a new type of amphibian. Apart from the financial value and the knowledge that one is helping science, the finder of a new species is usually commemorated in its name. Supposing a miner called Evans finds the skull of a new kind of *Orthosaurus,* an animal rather like a small crocodile, it will probably be called *orthosaurus evansi.* Or if he preferred to commemorate the name of Will Lawther or Arthur Horner, it could be called *Lawtheri* or *horneri.*

What I hope to do is to inaugurate a regular scheme of purchase from miners. Such schemes have worked very successfully elsewhere. Most of the fossils from the English Chalk have been found by quarrymen or lime-kiln workers, who have sold them to scientists. The great Thomas Henry Huxley got quite

a number of fossils of amphibians from the coal measures from miners or surface workers who knew of his interests. But unfortunately, there seems to be a gap between miners and palæontologists to-day.

It is quite possible that some miner may strike a rich deposit of fossils, and become a real expert himself. This has happened in one case. David Davies, a Welsh mine foreman, was the first to make really large collections of plant remains from different coal seams. He showed that even where the plants did not differ very much, there were differences in the proportions of different kinds, just as in one meadow you will find a great deal of clover among the grass, in another very little. I am glad to say that the University of Wales gave him an Honorary Degree for his work. Unfortunately, plant remains from coal seams are pretty common, and I am not prepared to pay for them, though I would certainly pay for insect remains, if any were found.

The nationalisation of the mines is only a step towards socialism, though it is a big one. Socialism in the full sense will only be possible when the workers in every industry understand enough about the conditions of their work to be able to control it, and in particular when most experts, such as engineers, geologists and medical officers, are drawn from the ranks of the workers. Now the study of fossils is absolutely essential for geology, because the different rocks are dated by the fossils in them. Naturally enough the geologists use the commonest fossils for dating. And the commonest fossils are generally shellfish. But shells are much less interesting to the student of evolution than bones. One cannot tell much about the animal that made it by looking at a shell. One can tell a great deal from bones. Some of the amphibians in the coal measures had lost their legs, and degenerated into eel-like creatures which could not come out of the water. Others had powerful legs and could lift their bellies off the ground. In a few cases from the French coal measures, we have enough specimens of a species to know that they started as something like tadpoles and only

developed legs as they grew up. Again the teeth show us what kind of food they ate. And just as some of the shells enable an expert to date a rock very accurately, the vertebrate fossils are characteristic of longer periods. If you show me an oyster shell I have not the least idea of its age. The oyster has not evolved much. It has stayed put for hundreds of millions of years. But if you show me three skeletons I can say that this one is probably a fish from the Old Red Sandstone, that one a reptile from the Jurassic and the other a mammal from the Eocene. So to get a broad view of geology one must study the vertebrate fossils, which show a fairly steady progress, as well as the invertebrate ones. Miners can begin to learn geology by studying the fossils from their own pit if they are lucky enough to find any. And by doing so they will be helping to raise the miners as a whole to the level of knowledge where they can take over the management of the mines completely.

I know that many people think that science should be severely practical, and that the detailed study of fossils is of no practical importance. This is quite untrue. Any bit of "highbrow" science may prove to be of the greatest practical value. For example the British coalfields were laid down near the sea. Some of those in France and all of those in Czechoslovakia were laid down in lakes well away from the sea. Naturally they contain very different fish and shells. So it is hard to say whether a Czech coal seam is earlier or later than an English one. But an insect could fly or be blown from one coal swamp to another. So we might be able to find out which seams were formed at the same time if we found the same insects in both. This sort of dating tells us about the structure of Europe in these ancient times, and suggests where to look for new coalfields.

But I believe there are a great many miners who are interested in knowledge for its own sake. It is just as interesting to know what fishes lived in Dinantian times (the technical name for the group of some million years during which some coal seams were

formed) as to know who won the cup final in 1937. Those who laugh at this kind of knowledge are simply trying to prevent their mates from knowing more than themselves, in fact keeping them down. They are playing into the hands of those who don't want the workers to have free access to all kinds of knowledge. By looking for fossils in your coal pit you will not only be helping science and perhaps earning some money. You will be helping to raise the status of your profession, and to break down the division of classes in British society.

I GET FOSSILS

Last month I wrote an article in *Coal* asking coal miners for fossils of certain kinds, and I am just beginning to get the results. Before saying anything about them, I want to say what I asked for, and why.

Fossils are of interest for two rather distinct reasons. In the first place they tell us about animals and plants which lived in the past, what they were like and how they had evolved. Secondly, they enable us to date rocks. Two beds which contain just the same set of fossils must have been laid down at much the same time, for evolution goes on quickly enough to produce marked, though not very striking, changes in half a million years; and the majority of rocks were laid down at a rate of less than 100 feet per million years, often very much less.

In just the same way a student of ancient coins may use them to study the development and degeneration of metallurgy or craftsmanship. Or he may use them for dating. For example in the cave called Wookey Hole, in Somerset, coins have been found which were made under 17 Roman emperors who reigned between A.D. 60 and 392, but nothing later until quite recent times. Clearly people lived there up to about A.D. 400, possibly refugees from the troubles which occurred when the Roman legions withdrew; but it was not inhabited in Saxon times or the middle ages.

Now I am trying to get fossils from the coal for my colleagues Kermack and Kiihne, who are palæontologists rather than geologists. That is to say they are interested in fossils for their own sake rather than for dating. In order to date rocks you had better study the commonest fossil species, which are generally molluscs or other similar shellfish. The commoner types of shell from the coal

measures are pretty well known. They are economically important because they help to identify corresponding coal seams in different areas. The fossil plants are also fairly well known, partly because there are a great many of them, as is natural since coal consists of plant remains, partly because they throw some light on how coal was formed, and have therefore been studied.

However, what my colleagues want are fish and amphibian bones and teeth, as they tell one a great deal more about the animals to which they belonged than do shells of animals resembling mussels. I have offered to pay for fish or amphibian remains provided I am told just where they were found, so that we can organise a search for more, if anything interesting is found.

Unfortunately my first few parcels have mostly consisted of plant remains, with a few molluscan shells. No bones have yet turned up. There is however one beautiful little animal related to the living king-crab. It looks rather like a very large wood-louse. However, as a matter of fact it was more nearly related to the spiders and scorpions. I shall certainly sell it to a museum and let its finder have the price, though I fear it will not fetch more than a pound or so.

At least one of those who have sent me fossils obviously knows something about the subject, and with a little luck may get something important. I am afraid some of the others will regard me as a swindler because I am not prepared to pay for shells of molluscs, even though they are called shell fish.

I did my best to make it clear just what I wanted, but I obviously did not succeed very completely. Also some of my correspondents may have mistaken tree bark for fish scales. This is not their fault. Palæontology is not taught in schools, and what is worse, men and women who regard themselves as educated are often totally ignorant of it. This is largely because our educational system is totally pre-scientific. Our wretched school children have to learn whom Edward II married and why this

provided Edward III with an excuse for invading France. They have not the vaguest idea what their ancestors looked like fifty million or two hundred million years ago. I don't regard the ancestry of the human race as certainly established, but it is better established than the legitimacy of Edward III, to judge from what has come down to us about the private lives of his parents.

Even if I became Minister of Education, we could not start teaching children palæontology because it is quite possible to become a qualified teacher of science without knowing anything about it. But I should see to it that future teachers learned a little of this science, even if they had to miss the kings of Judah and Israel.

Above all, miners and quarrymen ought to know some, just as engineers ought to know some physics and chemistry, farm workers some biology, and seamen some meteorology. It is not merely that it may be useful. A self-respecting man or woman ought to understand what he or she is doing. Otherwise they are half way to being slaves.

Of course there are good reasons why workers are discouraged from gaining such knowledge. For one thing it would put them on a level with much more highly paid experts. For another they would probably learn about the economics of their job as well. And this kind of knowledge does not make for the stability of capitalism. But I want to see the miners learning all that is necessary to take over their industry completely. Economics is one thing they will have to learn. Palæontology is another.

THE EARTH SPINS

In the series of articles of which this is the first, I am going to say something about the observed facts behind astronomical theories. We are taught in school that the earth goes round the sun, that the light from the nearest star takes several years to get here, and so on. We ought not to take such statements on authority. We ought to know something of the evidence on which they are based, and even to check it if we have the opportunity. Otherwise we shall get into the very dangerous habit of believing any story that we hear often enough.

I am not going to go into the evidence that the earth is round. The fact that maps are good guides to action, and are made on the basis of its roundness, should be sufficient. It would make all the difference to world politics if the earth were flat. It would mean that there were new regions to be found, and that ambitious statesmen could annex them instead of invading their neighbours. But it is not so obvious that the earth spins round once a day, or what difference it would make if it did not. Until recently people thought that the sun, moon, and stars spun round the earth once a day. The stars were supposed to be stuck to a solid object called a firmament. Children learn about the firmament in Bible classes, and unlearn it in Science classes. Centrifugal force would produce a fearful strain in the firmament, but perhaps if there were a firmament it could stand it. And when Copernicus argued that the earth went round and the stars did not, he could only urge that this view made astronomy easier to understand.

The first good bit of new evidence for the theory arose when it was shown that pendulum clocks went slow in the tropics, and that there were more yards in a degree of longitude near the equator than in France, more in France than in Arctic. That is to say

the smallest distance between two points on the earth's surface such that the maximum "height" of a particular star above the horizon is one degree higher at one than the other increases as you go to the equator. This is at once explained, and what is more explained quantitatively, if the earth's spin makes its equator bulge out. The combination of centrifugal force and greater distance from the centre lessens the force of gravity, and slows down a clock regulated by a pendulum, but not one regulated by a hairspring. A turning firmament might have some effects of this kind, but it would be very strange that it should have just the effects calculated if the earth turns once daily.

Another striking confirmation came from the study of winds. Air moving away from the North Pole has no motion due to the earth's spin. So as it goes southward the eastward-moving earth leaves it behind, and from being a north wind it becomes a north-east wind. In fact it turns right. The cold air descending in an anticyclone in the northern hemisphere moves right as it spreads out, so the anticyclone or "high" turns clockwise, and a cyclone with warm rising air turns anti-clockwise. The opposite is true in the southern hemisphere. Ocean currents and ice behave in the same way. A north wind in the Arctic Ocean drives the ice-floes south-west.

Probably the most dramatic of all the proofs of the earth's rotation was the experiment which Foucault made a hundred years ago with a very long pendulum suspended from the dome of the Pantheon in Paris. The pendulum, which was merely a weight on the end of a rope, was set swinging and left. Common sense suggests that so far as possible the pendulum will keep swinging in the same plane, or at least in a series of parallel planes, and physical theory supports common sense. The question is whether "the same plane" is fixed relative to the earth or relative to the fixed stars. When the experiment is done (and you can see it repeated any day at the Science Museum in London) the plane of swing moves relatively to the building, but keeps as steady as it can relative to the stars.

So it can be used as a clock like a sundial, though actually it is not so accurate. On the other hand the gyro compass, which is based on practically the same principle, namely that a spinning body given the necessary freedom will keep its axis pointing in the same direction, is very accurate, and of course very useful in aeroplanes. It is most remarkable that nobody did the pendulum experiment before 1851. It involves no mathematics until one tries to calculate the small allowance to be made for friction. All it needs is a large building with no serious air draughts, so that the pendulum can go on swinging for some hours.

A much more difficult experiment is this. A pair of metal weights on the end of hinged arms is suspended from a thread or wire. At first the arms are held out so that the weights are as far apart as possible. Then a thread which holds them up is cut or burned through. They fall until the arms are hanging vertically. In consequence the whole system begins to turn in the same direction as the earth, that is to say opposite to the sun's apparent motion. This is due to the conservation of spin, or angular momentum. The system is turning once a day with the earth. When the weights drop, the amount of spin remains the same, but it has a system with less moment of inertia to move, since the whole mass of the system is now concentrated near its axis. So it turns more quickly. The principle involved is the same as that of a flywheel. The mass of a flywheel is as far away from its axis as possible. So for a given number of rotations per minute it has a great deal more spin than if it were near the axis. It is harder to stop it or to set it moving.

Finally if Blackett is right in his recent guess that all spinning bodies are magnets, whose strength is given by a law which he states, the earth's magentism is a further bit of evidence that it is spinning.

If we lived in caves, and had never seen the sun, moon or stars, but had made the other necessary observations, the hypothesis of the earth's rotation would probably be something which most

scientists believed, but which one could doubt without raising any suggestion that one was mentally abnormal. If some of these caves communicated with the sea, so that the tides could be observed, a few daring thinkers would probably have deduced that there were one or two heavy bodies outside the earth. But they would not have calculated their sizes or distances. A sufficiently perverse and ingenious believer in a fixed earth and a moving firmament could perhaps have produced theories to explain all the facts so far given, and several others which I have not mentioned.

There is one set of facts, however, which seems to me conclusive. We can calculate the times of eclipses for some years ahead with an error seldom more than five seconds. We can also calculate the times of past eclipses. When we do so by the same methods we may be several hours out, when we get back to eclipses over two thousand years ago whose times have been recorded. This error is cleared up if we suppose that the earth's motion round its axis is slowing down, so that every hundred thousand years or so the day is a second longer. This slowing is exactly accounted for by the friction of the tides, which act as a brake on the earth. Of course the movement of the firmament might be slowing down. But it would be an altogether incredible coincidence if it were slowing down at just the rate calculated from the known facts about tidal currents and the known mass of the earth.

I will next deal with the evidence that the earth really does go round the sun, and that this is not just a convenient way of explaining astronomical observations.

THE EARTH GOES ROUND THE SUN

I shall now try to give the evidence for the statement that the earth goes round the sun once a year in an orbit nearly two hundred million miles across. The evidence is not quite so strong as for the theory that the earth turns round once a day, because linear motion is not so easy to detect as spin.

If you look at the moon at the same hour on consecutive nights, you see that it lags relatively to the sun. Each day it rises and sets, on an average, nearly an hour later. Similarly the sun lags about four minutes a day relatively to the stars, and the other planets lag by different amounts. Naturally we set our ordinary clocks by the sun, not by the fixed stars. But the stars keep much better time than the sun. The length of a sidereal day, that is to say the time between two occasions when a "fixed" star is in the same direction relative to objects on the earth, is extremely steady. The length of a solar day varies throughout the year.

All these things are explained, and can be very accurately calculated, if the earth and planets move round the sun, and the moon round the earth, in elliptical orbits, according to Kepler's laws. There are two corrections to be made to these. The orbits are not exactly ellipses, because the planets are attracted by one another according to Newton's laws as well as by the sun. And Einstein's modification of Newton's laws embodies a much smaller correction. Still the apparent motions would be just the same, though no simple theory could explain why they occurred, if the earth were still, the sun moved round it, while the other planets moved round the sun.

There are however several facts which do not fit in with this view. One is the fact called aberration. If rain is falling

vertically and you run through it, it seems to slope towards you. In other words it seems to be coming from in front of you. Starlight behaves in the same way. The apparent directions of the fixed stars vary once a year. Those of all the distant ones vary similarly, and the variation, which is called aberration, is just what is calculable from the speed of light and the speed of the earth in its orbit. Aberration would be quite unintelligible if the earth were fixed.

Besides aberration, there is another apparent annual motion of the nearer fixed stars, which is called parallax. They seem to shift, in the course of a year, against the background of the farther ones. This confirms the theory of the earth's motion, but does not enable us to measure it, because it is only by measuring parallax that we can find out how far off the stars are. Still another light effect tells the same story. If we are moving towards a light, any particular line in its spectrum is more refracted, and would even appear bluer if the speed of approach was very great. This is because more waves reach us from it in the course of a second. Now the earth is moving towards those stars which we see to the south about 6 a.m., and away from those which we see to the south about 6 p.m. And the light from the same star is measurably, though not perceptibly, bluer when we are moving towards it than when we are moving away.

Yet another bit of evidence comes from shooting stars or meteorites. These are bits of stone or metal which fall into the air from space. We should expect to sweep up more of them in the part of our atmosphere which is moving forwards than in the part which is backing. And so we do. Not only are meteorites commoner just before dawn than just after sunset, but they are moving faster. It would take a very ingenious theorist to explain why this should be so if the sun moved round the earth.

The scale of the solar system can be measured in many different ways. It is quite easy to find out how far off the moon is.

You can photograph it simultaneously against a background of stars in England and South Africa, and see at once that it has shifted, as a near object changes its position relative to its background if you look at it first with your right eye and then with your left. It is not so easy to find out how far the sun is. Occasionally the planet Venus passes directly between the earth and the sun, and can be seen as a black dot. By comparing the time taken by Venus in a transit, as this phenomenon is called, as seen from different parts of the earth, the sun's distance was fairly accurately measured in the eighteenth century. Since then it has been measured much more accurately by observations on several minor planets too small to be seen without a telescope, which sometimes come very much nearer to the earth than Venus ever does.

The aberration of starlight gives us yet another measure, not quite so accurate. So does the lag of about 16 minutes in the times at which Jupiter's satellites are seen to be eclipsed when the earth is farthest away, compared with when it is nearest. The important point is that all these methods tell the same story. The fact that they do so makes us trust the methods concerned when we can only use one at a time, as is the case when we get to the distances of the "fixed" stars.

There is one set of methods which tell us nothing. We get no answer if we try to find out how quick the earth is moving through space, though we can find out how quick it is moving to or from another body. This fact is the basis of the theory of relativity, which means, in simple words, that space is less real than matter. Strangely enough, however, though there does not seem to be such a thing as absolute position, motion or rest, there is such a thing as absolute direction. One can detect spin apart from any influence of external bodies.

Incidentally, the scale which we find for the solar system tells us that the earth is an average sort of planet. Mercury, Venus or Mars are smaller, Jupiter, Saturn, Uranus and Neptune bigger,

Pluto about the same size. The mountains on the moon are about as high as those on earth, though much steeper, as there is no rain to wear them down. All this makes sense. The properties of matter seem to be just the same in one part of the universe as in another. Common sense sometimes lets us down, but not very often.

In the next few years it is probable that we shall know these distances much more accurately by radar. Echoes from the moon have already been picked up, and it should be quite possible to measure the distance of the nearest part of its surface within a few miles. A similar experiment with Mars, Venus or a minor planet would be vastly harder, but not necessarily impossible. The sun is already sending out so many radio waves that it would be much harder to pick up echoes from it with the necessary accuracy. We shall next deal with distances and sizes of things outside the solar system, and see that they make sense too.

THE NEARER STARS

The nearest star to our solar system which is at present known is in the constellation called the Centaur, so far south that we never see it in England. This star is about 1¼ parsecs away. Astronomers measure distances in parsecs. It takes light about 3¼ years to travel a distance of a parsec.

At a distance of one parsec the position of a star relative to the more distant ones behind it, shifts through an angle of one second relative to the more distant ones behind it as the earth moves round the sun in the course of a year. This is one three thousand sixhundredth of a degree, or the apparent size of a halfpenny three and a quarter miles away. A shift of far less than this is readily detected on comparing photographs taken at intervals of six months. Most of the nearer stars also move quite perceptibly against their backgrounds in a few years. This effect is due to their own motion, not to the earth's. Thus if we know their distances we can calculate the speeds at which they are moving at right angle to the line of sight. These speeds are reckoned in miles per second, which compares, with the earth's speed of 17 miles per second along its orbit.

Now we can also measure the speeds of these fixed stars along the line of sight by means of the Doppler effect, that is to say the blueing of light from an approaching object, and the reddening of light from a receding one. The average speed in the line of sight is a little less than the average speed at right angles, so the whole calculation makes sense.

Again we can calculate the amount of light which a star would give if we were as near to it as we are to the sun. One finds that some stars are much brighter than the sun, and some much

dimmer. Now the stars can be classified both by their colour and by the elements which can be detected in their atmospheres with a spectroscope. Some of them have spectra very like the sun. All the sun-like stars whose distances are known turn out to give out light at about the same rate as the sun.

In fact the results of astronomy go on making sense. The sun is a fairly typical member of a large class of natural objects. Most results of scientific research of this kind. They check up on one another, and make nature appear more natural.

But enough strange and unexpected results are known to keep scientists busy. The same calculations which showed that the sun is a typical star of its kind showed that some other stars must be enormously bigger than the sun. We know their surface temperatures, and therefore the amount of light which they emit per square mile, from their colours. Some which have cooler surfaces than the sun, put out thousands of times more light per minute. So they must be so large that there would be room for the earth's orbit inside them.

If so it should be possible to measure their diameters, not directly, but by the phenomenon called interference, which is also used for measuring very small distances, for example the thickness of a soap bubble. It was used to measure the very small angle subtended at the earth by the giant red star Betelgeuze in Orion, and gave the expected result. Since then several more diameters of large stars have been measured in the same way.

Something like a third of the stars are probably doubles, that is to say they consist of two sun-like objects moving round their common centre of gravity in ellipses, as they should according to Newton's laws. If we assume that the relation between mass and gravitational force is the same among the distant stars as in the solar system, we can determine the masses of a pair of stars whose distance is known.

No one was surprised when it was found that stars with the same colour and spectrum as the sun had about the same mass as the sun. But astronomers were very surprised indeed when they found that all the stars without exception had about the same mass as the sun. The agreement is only rough. Few stars are ten times as massive, none known to be a hundred times as massive, as the sun.* Some have only about a tenth of its mass. The luminosity of a star, however, increases much more than in proportion to its mass. A star ten times as massive as the sun gives out about 1,000 times as much light.

The reason for the close relation between mass and luminosity was largely explained by Eddington, but is a little too complicated to give here. The reason why no stars are much larger than the sun is a simple one. A very large star would generate so much heat that it would burst, and the double and triple stars are probably stars which have burst. So perhaps are clusters of stars like the Pleiades. Other stars are quite unexpectedly small and dense. There may be plenty of stars whose mass is less than a tenth of the sun's, but if so they give out so little light that we have not yet detected any of them.

Once the relation between mass and luminosity for the stars of known distance and mass was known, it was applied to the stars in general. In fact we have only to measure the brightness of a star and to observe the spectrum and colour, to tell roughly how large it is, and how far away.

However, before this relation was known, another method was available. Some stars are variable because a companion star occasionally eclipses them, others because they pulsate regularly, swelling up and collapsing again in the course of a few days. These are called Cepheid variables, after Delta Cephei, a star in the Milky Way not far from Cassiopeia. There are a lot of Cepheid variables

* At least one is now known with over 100 times the sun's mass

in one of the clusters in the southern sky called the Magellanic clouds. Miss Leavitt found that all those in this cluster with the same period had the same brightness, and that brightness and period varied together in a simple way.

As the distances of some of the nearer ones were measured, it was found that this was a general rule. So one can calculate the distance of any Cepheid variable when one knows its period. As all Cepheid variables are very bright stars, this enables us to measure distances much too great for the parallax method. In fact they have been used to measure not only the sizes of he Milky Way but the distances of the nearer galaxies outside it.

The main difficulty with these indirect measures is that there is a good deal of dust in the space between the stars. When I say a good deal I am speaking in a "Pickwickian sense". The light from a star has to travel for thousands of years through one of these dust clouds before half of it is stopped. However the spaces concerned are so vast that the amount of matter in these dust clouds may be greater than that collected in stars. It is possible that this dust is constantly forming new stars by condensation.

All these discoveries about the distances of the stars hang together to tell a coherent and fairly simple story. But when we get to still greater distances there are real difficulties, with which I shall now deal.

SEEING THE PAST

The stars in our immediate neighbourhood, including most of those which we can see, are about equally dense in all directions. But when we look through a telescope we see that the Milky Way consists of million of stars and that faint stars become commoner as we get near to it.

Besides this general concentration of stars there are star clusters of two types, namely open clusters like the Pleiades, and dense or globular clusters of which the few visible with the naked eye look like single stars, and only a telescope shows that they consist of many thousands of stars. These clusters contain Cepheid variables which enable us to measure their distances in the way which I explained in the last article. The open clusters are near the Milky Way, and the farthest yet detected is about 500 parsecs away. In other words the light which we see from it started out about A.D. 300. The globular clusters are much further off, up to 50,000 parsecs, and are not found near the Milky Way. The light from them always started before the beginning of human history, and generally during the Ice Ages.

A careful statistical study of star motions makes it very probable that the stars in our neighbourhood, including the sun, are moving round the centre of the Milky Way, which is in the constellation Sagittarius, probably in spiral rather than elliptical orbits. The distance of the centre is about ten thousand parsecs, and we go round it once in two or three hundred million years. That is to say we have been round about once since the Coal Measures were formed.

The whole system of all the stars which we can see with our eyes or with an ordinary telescope is a biscuit shaped object about

five thousand parsecs thick, and perhaps thirty thousand across. The sun is about half way between the centre and the edge. The Milky Way is just the appearance of immense numbers of stars which we see when we look in the plane of the "biscuit". The globular clusters lie out in a sphere roughly enclosing the biscuit. The mass of the whole system is something like two hundred thousand million times that of the sun, and there are probably about five times that number of stars in it. This is about a thousand times the total number of men and women, and about equal to the total number of birds.

In the direction of the Milky Way we cannot see what is beyond it, owing to the clouds of stars and of dust. But in other directions we can see a few rather faint objects and photograph tens or thousands of them. These are the so-called spiral nebulae. The most easily seen is in the constellation Andromeda, and though it is very faint, its apparent size is larger than the moon's. With a good telescope it is seen to consist of stars arranged in a rather irregular spiral. Among the brighter stars in it are some Cepheid variables, so its distance can be measured, and consequently its actual size. It turns out to be about as large as the Milky Way, and to be so far off that the light which we now see from it started about nine hundred thousand years ago, that is to say at the end of the Pliocene era, before the Ice Ages, and before we know of any fossils or tools which are certainly human.

The distances of hundreds of other spiral nebulae have been measured with less accuracy. They are all of about the same size. When their spectra are photographed, they are all seen to consist of the same sorts of elements as are found on earth, and to be spinning round like so many catherine wheels. They are quite unlike the stars in one important respect. The distances between stars, even in a dense cluster, are very much bigger than their diameters. On the other hand the distances between neighbouring spiral nebulae are often only about twenty times their diameters, and sometimes less.

There is, however, one very queer thing about them. The spectroscope shows that the light from them is reddened, not by a scattering of the blue light, as in the case of the setting sun, but by lowering of the frequencies of vibration of light of all kinds. This could be explained if they were all moving away from one another, that is to say if the universe were expanding.If so the farthest ones yet photographed are moving away from us at about an eighth of the speed of light.

It could also be explained if in the course of time the movements of electrons inside atoms were speeding up, so that a particular type of event in an atom, for example the approach of an electron towards the nucleus of a sodium atom which gives the yellow light of some street lamps, gave out more energy to-day than in past geological ages. Milne showed that these two ways of describing the same events are not really different, but depend on different ways of measuring time and space. In fact an extension of the theory of relativity seems to solve this problem, though it raises new ones.

The farthest spirals so far photographed are so far off that the light which reaches us from them has been travelling since Permian times, just after the coal was formed. With the great new mirror which has been made for the observatory at Palomar in California, it will be possible to photograph light about twice as old, that is to say Cambrian light. It may well go still further into space, and back into the past.

This will allow us to measure the rough distances of most of the nearest million or so spirals. According to some theories, for example Eddington's, the total amount of matter in the universe is finite, and if we could photograph things only four times as far away as this we should find they were moving away with almost the speed of light. According to other theories, such as Milne's, the amount of matter in the universe is infinite. This of course could never be proved. But it may be possible, within our lifetimes, either

to prove that Eddington was wrong, or that so far his theory has led to correct predictions.

The important point is that such question as these are not questions to be argued about forever by philosophers, but questions to be settled by observation. The apparatus needed will cost some million of pounds; but the settling of such questions has always given us enough new knowledge about matter to be well worth while.

In science we always find regions where our knowledge is clear, and others where it is far from certain. One of these is of course the study of things very far off in space or very far back in time. These are really the same problem in different words. When we can photograph objects eight or ten times as far off as now we shall be photographing them as they were at about the time when the earth was formed. Another region of uncertainty is concerned with extremely small distances and times. We get into this region when we study the nucleus of an atom.

There is still a third region of uncertainty. We can see things a little smaller than a wave length of light with a microscope, and we know about atoms and molecules from chemical experiments. But it is harder to find out about things larger than molecules but much smaller than wave lengths of light. And it is just in this region that the transition between chemistry and life occurs.

My own work lies largely in this third region. But it is amazing how rapidly our knowledge has extended, both concerning large and small things, in my own lifetime. We have got somehow to make this knowledge part of the heritage of ordinary people. The best way to do this is not to use large numbers, but ideas which should be familiar to every educated man or woman, such as the size of the earth, or the time since the coal or chalk were formed.

COMMON SENSE ABOUT THE PLANETS

In the development of science there is a constant and fruitful struggle going on between two tendencies. On the one hand we should like to explain everything, that is to say to find a reason for it. Geologists do not believe that it is either because of pure chance, whatever that may be, or an arbitrary act of creation, that the Thames bends to the right between Lambeth and London city. But they would equally agree that we do not yet know why it does so, and that any theory is likely to be wrong, and if generally accepted, likely to hold up the progress of geology. So although it is an excellent thing to find the right explanation, it is quite reasonable to say that we do not know the explanation, and had better for the present confine ourselves to describing things as they are.

A very good example of this fruitful strife is found in the history of our ideas about the solar system. For thousands of years men have known that there could see the sun, the moon, and five other planets. Actually you can sometimes see an eighth, Uranus, if you know where to look. Early men said there were seven planets because there were seven gods each identified with one of them. When their motions were described people asked why they moved as they did, and why there were just so many.

Kepler tried to answer the question. He thought that Mercury, Venus, Earth, Mars, Jupiter and Saturn each moved in a sphere with the sun as its centre, and the spheres were so arranged that one of the regular solids would fit in between two of the spheres. As there are only five kinds of regular solid, of which the cube is the best known, there could only be six planets. Kepler found that this theory wouldn't work, and later found the correct shape of the orbits, or very nearly so.

Newton showed why the orbits have the shape they have, and why a planet at a particular distance from the sun must move at the speed it does. But he did not try to explain why the known planets were at the distances calculated. He thought that this was due to the act of the Creator, though once created, their later motions could be explained.

Hegel explained why there were just seven planets. Unfortunately for him, a lot more have been found since, and no one takes his theory seriously. But he was quite progressive in supposing that the structure, as well as the motions, of the solar system, must have a rational explanation. An astronomer called Bode produced a "law" or rule for the distances of the planets from the sun. But it is only very roughly true, and if it were quite true, no one has suggested a reason why it should be.

This year a bit of real progress has been made by Kuiper, of Yerkes Observatory, who points out that there is a relation between the masses of the planets and their distances, and that this also holds for the satellites of the great planets Jupiter, Saturn, and Uranus. If the planets were formed from the condensation of dust or gas whirling round the sun, or from the breaking up of a filament shot out of the sun when another star passed near it, or in several other suggested ways, then the heavier a planet, the bigger the gap should be between it and its neighbours. For a heavy planet would not only use up more of the available matter, it would attract the matter in its neighbourhood, and prevent the formation of other planets near it. There are other more complicated arguments which suggest what the relation between masses and gaps should be.

So here is what Kuiper did. He added together the weights of each pair of neighbouring planets, for example Venus and Earth, Earth and Mars, and divided by the weight of he sun. He also calculated the differences between the average distances of these planets from the sun, divided by the sums of these distances. So he

got two columns of figures, and found that they fitted pretty well to a relationship derived from theory. Then he did the same for the systems of the moons moving round Jupiter, Saturn and Uranus. He found that the numbers followed the same rule.

In fact the rule which they fit is not quite what would be expected on any theory yet suggested, though one simple theory is nearly right. The rule finally arrived at is not completely accurate either. In fact only about half the distances calculated are within ten per cent of the true values. But that is something to be going on with. Fortunately for science, we shall soon have the means of finding out whether Kuiper's rule is really universally valid. Slight irregularities in the motions of some of the so called fixed stars, which of course are distant bodies like our own sun, seem to show that they too have planets. When the distances and masses of these planets are measured, if they conform to Kuiper's rule we shall have to take it very seriously. Meanwhile it may perhaps be made more accurate, by taking account of all the planets or satellites in a system, not only immediate neighbours, and by finding a more complete theory to account for it

The important point is that Kuiper's work justifies the view held by all Marxists, and a great many scientists who are not Marxists, that there are no arbitrary features in the universe, that is to say facts for which no rational explanation can be found. Of course at the present time we can only find a rational explanation for a tiny fraction of the known facts. And no doubt a lot of the explanations which we give will turn out to be wrong when we know more facts and think more clearly about the known ones. But we are right to ask why the earth goes round the sun once a year, and Jupiter once in eleven years, why male and female lions differ more in hair length than male and female tigers or cats, why sugar and glycerine taste sweet and alcohol does not, and so forth. We don't know the answers to these latter questions, but such work as Kuiper's makes us hope more firmly that our descendants will know them.

LOOKING FOR BLUE STARS

Two American astronomers, Humason and Zwicky, of Mount Wilson Observatory, in California, have recently reported a hunt for faint blue stars in two areas of the heavens. One was in the neighbourhood of the Hyades in the constellation of the Bull, where stars are very thick. The other was in the constellation Coma Berenices, as far away as possible from the Milky Way. They photographed the same area of sky, first through a yellow glass and then through a violet one, and picked out the forty-eight stars which appeared much brighter through the violet than through the red screen. All these stars were very faint indeed. Even the brightest was twenty times too far away to be visible with the naked eye.

Readers may well ask what can be the point of such a search, and even if it has more point than looking for the bluest postage stamps what possible practical value it can have. The answer is quite simple. The bluer a star, the hotter it is as a general rule. The reason is straight forward. As one heats a black object up it begins to produce invisible infra-red rays which can be felt as heat. Then it becomes red-hot, and later white-hot. Still hotter things give blue light. Thus an arc lamp is much hotter than a filament lamp, and much bluer. Of course many modern lamps, for example neon, mercury and sodium lights, shine because the atoms in them are electrically excited, not because they are hot, and their colour obeys quite different rules. But since blue light consists of more rapid oscillations than red, it is quite natural that a hot body, whose atoms are moving quickly, should give bluer light than a moderately hot one.

So what Humason and Zwicky were really doing was looking for the hottest bodies in two regions of the universe.

This is a reasonable thing to do, because matter under extreme conditions develops new properties (the change of quantity into quality). For example some very cold metals become super-conductors with practically no resistance at all, so that an electric current induced in a lead ring in a bath of liquid helium will go on circulating for hours on end.

The spectra of these stars were photographed, which made a calculation of their temperatures possible according to a principle first laid down by the Indian astronomer Saha, and worked on in more detail by Milne and Fowler in England. In a number of cases their so-called proper motions, that is to say the rate at which their directions in space alter, were already known. This made it possible to pick out those which were near to the sun, near that is to say in an astronomical sense. For a near object does not have to be moving very fast to alter its apparent position noticeably in ten years or so. So most stars which change their position quickly are fairly near to us.

In fact most of the blue stars in the Hyades shared the motion of Aldebaran and the other bright stars of this cluster. So they must be very much dimmer. It turns out that they belong to the group of stars called White Dwarfs, which are extraordinarily dense.

The matter in them is so closely packed that a cubic inch of it would weigh a ton. It is of course held together by its own gravitation, which is so enormous that even light has a good deal of work to do in getting out of such stars, and gets redder in the process, though not enough so to stop the stars being bluish white. Although no such star is bright enough to be seen without a telescope, they are so common near the earth that it is quite possible that there are more of them than of all the other stars put together. Searches in regions like the Hyades where there are a lot of stars will help to decide whether this is so. If so they probably represent a late stage of the evolution of stars, and perhaps our sun will finally contract into one.

The search for blue stars near the pole of the Milky Way gave quite a different result. A few are dwarfs, but most are very bright and large stars at an enormous distance. In the direction of the Milky Way there is so much dust between the stars that one can usually only photograph stars, however bright, a few thousand light years away. At right angles to the Milky Way one can see out into space beyond it. And some of these large blue stars may be a good way out in the almost empty space between our galaxy and its neighbours which we see as spiral nebulae.

So when more is discovered about them they may help us to fix the scale of the universe more closely, as well as telling us more about very hot matter. When I say very hot, I do not mean as hot as the matter in the first millionth of a second of an atom bomb explosion, or the matter of an exploding star, but the hottest matter which is on permanent display.

I don't know what will come out of such studies, or whether anything will. I know that the study of matter in the sun told us of the existence of one new kind of matter, namely the gas helium, and taught us much about the behaviour of the commoner kinds. In particular, in the sun and other stars we study matter in a much simpler state than is common on earth, that is to say as gas consisting of single atoms, many of which have lost one or more electrons. Their study has been of immense help in laying the foundations of chemistry.

Whether knowledge obtained in this way will be used for good or evil does not depend on the astronomers. Unfortunately so, because they are very internationally minded, much more so than chemists, for example. Star mapping, and particularly eclipse observation, are international matters, planned for many years ahead by the workers concerned, and workers in other jobs might well learn a lesson from the International Astronomical Union. In fact when miners, transport workers, or above all, agricultural workers, have as good international tie-ups as astronomers, our planet will be a much happier place.

RADIO FROM THE SUN

As radio signalling and broadcasting developed, attention was more and more directed to noise, that is to say unwanted disturbances. Some were shown to come from electric motors and dynamos, others from thunderstorms.

But finally it became clear that others came from outside our atmosphere. Jannsky's discovery of this fact was not at first followed up. But the development of radar and short wave transmission during the war led to a fairly intensive study. As it also led to secrecy the actual advance in knowledge was probably no greater than what would have been made in peace time. Now however a good deal of work is being done on the question, and a young and vigorous group of Australian physicists is playing a leading part in it.

Our atmosphere is opaque to most kinds of radiation. The sun sends out a lot of hard ultra-violet rays, and also very probably some X-rays. If we tried to live on the moon, which has no air, they would be very dangerous. Only two sets of rays get through in any quantity. One is in the visible region and the neighbouring parts of the infra-red and ultra-violet. We can see many of them, and photograph the others.

The other group consists of radio waves with lengths round a metre ranging from about a centimetre to ten metres or so. Some of these come from the sun, others from regions of the Milky Way where the stars are very dense. It is striking that whereas starlight is a negligible fraction of sunlight, the stars do not contribute much less than the sun to radio noise at normal times.

The sun's radio emission is of two kinds. One kind, with a maximum intensity about 3 metre, is fairly steady. The other kind,

with a maximum about 5 metres, is very much stronger, but only occurs when there are large spots on the sun's disc. If the same thing happened with regard to light, the sun would usually give white light, but from time to time there would be a terrific red glow.

On January 29th 1948, the Royal Society held a meeting at which Ryle and Vonberg, of Cambridge, communicated their results on accurate measurements, while Martyn, an Australian, produced a mathematical theory of the origin of the waves. Martyn's theory is something like this. The radio which we pick up in the absence of sunspots does not come from the luminous surface of the sun, but from the very thin atmosphere round it, which is called the corona, and can be seen when the sun is totally eclipsed.

When we go up in an aeroplane the air gets colder, but at great heights the air becomes very hot. The hot layers are the ionospheres, which reflect long radio waves downwards. The corona is the sun's ionosphere, and to judge from its light spectrum is enormously hot, with a temperature round a million degrees, and very strongly ionised. The radio emission is due to disturbances in it. Its electrical charge is so high, and the speed of its movements so great, that it gives rise to radio emission.

The difficulty in proving this, or any other theory, is that it is very hard to get exact directional radio reception. You are doing well if you can distinguish between sources a degree apart. If your eye were no better than this, you could not see a half penny at a distance of five feet. When the emission is pretty weak, as it generally is from the sun, things become particularly difficult, and Ryle and Vonberg worked out a most ingenious method for distinguishing solar radio from other noise.

If Martyn is correct, when we get a real radio telescope which distinguishes directions as well as, say a very short-sighted man can do, we shall "see" the sun as a fairly bright disc

surrounded by a very bright ring. For most of the radio seems to come from the edges of the corona. This is borne out by the few observations made during eclipses. There is a partial radio eclipse before any of the sun's light is cut off, and the radio emission is never totally eclipsed. In future radio observations during total eclipses are likely to teach us as much as, or more than, observations made with the eye or telescope. Whether the emission caused by sunspots comes from the spot itself or the corona above it remains to be seen. As there will be a maximum frequency of sunspots next year, we ought to know fairly soon.

What impresses me most about this work is its philosophical importance. For thousands of years people only knew about the sun, moon and stars by their light and heat. They formed all kinds of fantastic theories about the heavens, some of which were incorporated in religions.

Then Newton showed that the tides were due to the gravitational attraction of the moon and sun. Later Pallen gave the first accurate account of meteorites, objects from outside the air. Thousands have since been examined, and found to be made of ordinary matter.

Now we have a fourth way of exploring the universe. I do not know what people will discover with it. If I wanted to be sensational I would suggest that the solar radio noise was the confused records of radio messages by intelligent beings - angels if you like - living in the sun. I think this is most unlikely. But I also think that when we have real radio telescopes we shall discover much queerer things than that with them.

The world is full of queer things, but they are not a bit like what our ancestors imagined. For example some viruses, such as that of lethargic encephalitis, can make good children into bad ones, as devils were supposed to do. But devils were pictured as like men, though excelling them in power and wickedness.

Whereas viruses are half-way between living beings and chemical compounds, in fact much more alien to our ordinary thought than devils.

So I guess that astronomical radio research may, in time, tell us altogether fresh and unexpected facts about the universe.

COSMIC RAYS

On few subjects in modern physics is more nonsense written than on cosmic rays. To begin with, they are not rays in the ordinary sense of that word. They are a beautiful example of what you discover if you study the exceptions to ordinary rules. The whole electrical industry is based on following up two exceptions. Most unsupported bodies fall to the ground. But iron filings near a magnet, or scraps of paper near an electrified rod of sealing wax fall up.

When the usual rules governing the behaviour of electricity were worked out, another crop of exceptions turned up. Air ought to be a perfect insulator, and it may be for minutes at a time. But an air gap always starts leaking in the long run. Some of the leakage is due to ionisation of the air by high-speed particles flung out by radioactive atoms. But it was gradually shown that most of it is caused by something coming downwards. Hess and Kolhörster found that the leakage increased ten fold when they went up in a balloon to the height of six miles. Actually we now know that these "rays" consist almost entirely of very rapidly moving particles, and that at sea level about six of them pass through a horizontal square inch every second.

Three different instruments have been used to detect them. The Geiger-Müller counter, designed for work on radioactivity, is an electrically charged wire in the centre of a metal cylinder in a glass tube which discharges whenever a particle passing through the tube makes the air conduct electricity, or in technical language, ionises it.

The second is the cloud chamber invented by Wilson. A vessel with a glass window contains air saturated with water or

some other vapour. It is suddenly cooled by expansion, and the vapour condenses on any dust particles which may be present, forming a fog. After a few expansions all the dust is got rid of, and the condensation occurs on the trails of ions left by rapidly moving particles. These tracks can be photographed, and as soon as Skobelzyn, who recently represented the Soviet Union on the atomic energy committee, did so, he found that the so-called rays were really particles. Quite recently Powell, of Bristol, has developed special photographic plates in which cosmic rays make tracks which can be examined with a microscope.

The story of the analysis is told in Janossy's recent book.* Readers who know a little physics will find it good reading, but unless you know that MeV means a million electron-volts you are liable to stick on page 2, and there are several mistakes, notably the definition of a gamma ray on page 5.

One of the first steps was to couple up a number of Geiger Müller counters in series, so that a current only flows if they all start to leak at once. So if we have four such counters in a row it is very unlikely that current will leak in all four at once unless the same particle has gone through them all. Move one out of the row, and such coincidences become much fewer. If you put a screen of a couple of inches of lead above the counters, there are fewer discharges. If you put it below them, nothing happens. This shows that the particles come form the sky, not the earth. Very elaborate batteries, sometimes of dozens of these counters, have been set up, and it has been shown, for example, that when particles are stopped by a screen of lead, they often generate a shower of other particles, which may set off as many as five counters on the same level at once.

The modern theory of cosmic rays is very largely due to Blackett of Manchester, and a group of colleagues, many of

* *Cosmic Rays and Nucleic Physics by L.Janoassy, Ph. D. Press Ltd p.5*

whom, like Rossi and Occhialini, were refugees from fascism. Blackett and Occhialini first coupled up a Wilson cloud chamber with Geiger-Müller counters so that a photograph was taken just when a particle had passed through a particular set of counters.

In this way they could pick out, say, those particles which could just get through an inch of lead, but not two inches. Further, they could find out how fast the particles are going by various methods. The easiest to understand is perhaps the use of a magnet. A magnet will pull an electrically charged particle out of a straight path, but the quicker the particle is going, and the heavier it is, the less the pull.

The world's most powerful permanent magnet used to be in Blackett's laboratory at Birckbeck College, London. Now the most powerful ones are on Mount Alaghez in Armenia, where Alikhanyan and Alikhanov are working. Both are Armenians, and they are brothers, but one of them put a Russian ending to his name to avoid confusion.

When cloud chamber photographs were examined, the surprising result emerged that the "rays" consisted of several quite different kinds of particles. Some of these were electrons with positive and negative charges. But there were also much heavier particles. It was first thought that they were all of one weight, and they were called mesons. Now it is generally admitted that there are two different sorts of meson.

However Alikhanyan and Alikhanov say that there are at least fifteen different kinds of particle heavier than electrons, some being as heavy as ordinary oxygen or nitrogen atoms. They are moving at fantastic speeds, very near to that of light and break up in less than a millionth of a second. But in that time they can go through hundreds of feet even of rock. Unfortunately the Iron Curtain seems to operate at Dublin, where Janossy works, * for

* *Cosmic Rays and Nucleic Physics by L.Janoassy, Ph. D. Press Ltd p.5*

he does not refer to this recent Soviet research, though it was published before he wrote his book, and I should be the last to accuse him of suppressing it.

These particles, heavier than electrons, but most of them lighter than ordinary atoms, play a part in building up atomic nuclei, and seem to be among the things emitted when they explode. In fact their discovery links up with the research which has so far only given us atomic bombs, but will give us power for peaceful purposes also.

The origin of cosmic rays is completely mysterious. The original particles which cause them are mostly stopped high up in the air, and the particles observed at sea level are due to their hitting atoms on their way through the air. They do not come equally from all directions. The earth's magnetic field deflects some of them. But when this is allowed for they do not come from anywhere particular, for example from the sun or the Milky Way.

This fact is a serious gap in our knowledge of the universe, seeing that the energy absorbed by the earth from them is rather more than it gets from the light of all the stars together. In fact we are only at the beginning of our knowledge of them. We no more know where it will lead than we knew in the case of radioactivity fifty years ago. It is up to us to see that we make the kind of world where this knowledge will be used for human happiness and not for destruction.

WHY THE EARTH IS A MAGNET

During the nineteenth century physicists were constantly discovering new facts linking together the different properties of matter. Thus electric currents were found to produce heat and magnetism according to definite laws, and conversely temperature differences and changing magnetic fields were found to generate electric currents. These facts were discovered by such men as Ohm and Faraday as the result of dramatic experiments which could readily be repeated. These experiments gave the basis for much of modern industry; for example dynamos and electric stoves are merely developments of apparatus first set up to demonstrate the connection between different properties of matter.

In the twentieth century similar discoveries are made. But they can rarely if ever be demonstrated by a simple laboratory experiment like the glowing of a wire or the movement of a compass needle when a current is switched on. This is because they refer to the properties of very small or very large objects which only give effects on an ordinary scale indirectly. Sometimes this is because they are very small. For example the hot filament in a radio valve shoots out electrons which carry a current that can be varied by changing the potential of another part of the valve. But to understand what is going on, one has to learn to think in terms of electrons, which are much less familiar than electric currents, and much harder to demonstrate to the human senses. Sometimes the objects concerned are very large. Thus it has been shown that gravitational fields can bend light, and change its colours. But this was only proved by observations on the sun and stars using telescopes, and photographic plates on which careful measurements were made.

On May 15th 1947, Professor Blackett announced to the Royal Society what may be a new connection between the properties of matter, namely that all spinning bodies produce a magnetic field. He did not produce any experiments to prove it, but based his argument on the magnetism of the earth, the sun, and certain stars. It has of course long been known that the earth is a magnet. That is why one can find one's way with a compass.

The sun was first suspected to be a magnet because the streamers in the corona, which is seen round it during an eclipse, have a pattern like that which iron filings take up in the neighbourhood of a magnetized steel ball. It was proved to be a magnet after Zeeman had found that the spectrum of an element is altered by a magnetic field. The liens in the solar spectrum are altered in the same kind of way as those in a gas flame coloured by sodium if it is held between the poles of a magnet. The sun is a much more powerful magnet than the earth. In fact its magnetic field is about a hundred times as strong, and its magnetic moment is a hundred million times that of the earth.

This year Babcock of Mount Wilson Observatory, America, examined the spectrum of a star which on other evidence was believed to be rotating rapidly, and found the same distortion of the spectral lines, but enormously stronger than in the sun. The star in question turns round its axis about once a day, and the magnetic field appears to be about 1500 gauss. This is a considerable filed strength. If the earth had such a field, steel ships would set themselves north and south like compass needless and it would be very hard to steer them.

There is evidence that some small stars have magnetic fields far stronger than this, in fact stronger than any which have been made in a laboratory, let alone used in industry; but they have not yet been measured. The measured magnetic fields cover a range of 2,500 fold. The magnetic moment of Babcock's star is about ten thousand million times that of the earth.

Blackett's discovery is simply that the magnetic moment is exactly proportional to the angular momentum. That is to say if we know the mass and shape of a body, and the rate at which it is spinning, we can calculate its magnetic moment. To be quite accurate, the magnetic moment of the star is forty per cent more than it should be if calculated on the basis of the earth's, but the measurement are not yet very accurate, and an error of forty per cent in a factor of ten thousand million is not very serious. In other words every rotating body is a magnet. The magnetism cannot be due to rotating electric charges. If the earth had the charge needed to make it a magnet for this reason, there would be an electric field of millions of volts per inch at the surface.

If this theory is true, it may be asked, why can it not be demonstrated in the laboratory? The test would have to be made with a fly-wheel or sphere spinning so fast as to be very near bursting. Steel could not be used, and a non-conductor would probably have to be tried as well as a metal. Finally the field produced even by a bronze sphere ten yards in diameter spinning as fast as it safely could would only be about a millionth of a gauss, and extremely difficult to detect at all, let alone to measure accurately. It is unlikely that the experiments will be made for many years.

The theory may facilitate work on atomic nuclei, by helping us to understand how a neutron, though it has no electric charge, behaves as a magnet. More likely it will help in the framing of a cosmology which will link together gravitation and electromagnetism more satisfactorily than Einstein's theory of general relativity.

It is of some interest that Blackett carried out this work while president of the Association of Scientific Workers. The sort of man who becomes president of this union is one who does not keep his eyes glued to a particular job of work, but looks around him. So is the sort of man who finds out new facts about the universe.

THE CLASSIFICATION AND ORIGIN OF ANIMALS

I am constantly being asked questions about animals, and it is fairly clear that my questioners have never learned the elements of zoology. That is a severe criticism of our educational system. There are two good reasons why we should know about animals. The first is that many of us have to deal with them, though in modern cities most people have rather small chances of doing so. The second reason is that we are animals, though animals of a very peculiar sort, and we cannot understand ourselves and one another without understanding what we have in common with other animals.

One of the things which zoologists have to do is to classify animals. Every animal is assigned to a species. Roughly speaking a species means a group of animals which will mate without difficulty and give fertile offspring. Each species is given two Latin names. For example the sewer rat is called *Mus norvegicus.* The first name is the name of the genus *Mus*, which also includes the ship rat *Mus rattus* and the house mouse *Mus musculus.* They may be compared to human names like John Smith and Robert Smith. However a species is, or should be, a biological reality, a genus is a matter of convenience. Some authors put the house mouse in a different genus to the two rats.

Similar genera are put in the same family, similar families in the same order, similar orders in the same class, and similar classes in the same phylum. For example the genus *Mus* is assigned to the family *Muridae,* including various rat-like animals. The family is included, with squirrels, porcupines, beavers, and so on, in the Order *Rodentia,* or gnawers. The rodents are included in the class *Mammalia*, hairy warm-blooded animals which suckle their

young. The *Mammalia* are one class of the phylum *Vertebrata*, which agree in having backbones, and in many other characters. There are also intermediate divisions, such as suborders and subclass.

Now when such classifications were first made they were made for convenience, like the classification of words into nouns, adjectives, and so on. But when the theory of evolution was accepted, zoologists tried to classify together animals which they believed had a common ancestor. For example it is probable that all mammals are descended from members of one species of reptile whose organs underwent certain changes, while others stayed put. This is quite different from the classification of words, chemical substances, or human beings. Nobody thinks that all adjectives are descendants of a single adjective. On the contrary adjectives like wooden are made from nouns, and adjectives like eatable from verbs. We do find a trace of this idea when for example the Jews are described as the children of Israel, although we know that plenty of people not descended from Israel became Jews, so that Jews are of mixed origin.

However the classification of animals is not as logical as it should be and probably will be when we know more. For example the class of Reptiles has given rise to Mammals and Birds, as we know because we have found fossils of intermediate forms. In fact a bird is more nearly related to a crocodile than a crocodile is to a tortoise. That is to say you have to go farther back into the past to find the ancestor of all three groups than the common ancestor of birds and crocodiles. So the class of Reptiles is a group of animals which have stayed at a certain level of organisation, rather than all the living descendants of a common ancestor. A group made up in this kind of way is sometimes called a Grade.

In this series of articles I am going to describe the main groups of animals. But before I do so we must ask what an animal is. The simplest answer would be that an animal is a living thing

which can move itself about. This is generally true. But most animals pass through a stage where they cannot move. You and I could not move at all in the first few months of our lives before birth, and not very much in the later ones. An oyster swims about vigorously when quite young, but passes most of its life stuck to a rock. More serious still, some microscopic plants swim about throughout their lives, and some quite large plants such as seaweeds, start life as microscopic swimmers.

Others have tried to make the distinction on the ground of nutrition. Most plants use sunlight and carbon dioxide to make their living substance, while all animals have to feed on plants or on other animals. But so do the fungi and moulds, which are classed as plants.

In fact no sharp distinction can be made. There is a group of very small living beings called the Flagellata. They are single cells, often shaped rather like a tadpole, and swim about by lashing their flagellum, which corresponds to the tadpole's tail. Some of them are certainly plants. They only need water, light, carbon dioxide, and salts. Others are certainly animals. They have mouths, and eat other plants and animals. Some live on food in the water, but have not got definite mouths.

Biologists mostly believe that the animal forms have evolved from the plants. For plants must have existed before animals. Plants can live without animals to eat them, and animals need plants as a source of food. Quite recently it has become possible, in this group, to make animals out of plants in the laboratory. The attempt very often fails. Some plant flagellates, of the kind which make the water in ponds go green, stay green when kept in the dark and fed on sugar. Even after several years, and thousands of generations, in the dark, they stay green. Others lose their green colour, but regain it within a few hours when put back in the light. This is quite in accordance with Weismann's theories.

But when other kinds are kept in the dark, the number

of green plastids which are the organs for using light to make sugar, diminishes. It may diminish so much that when a cell divides one of the daughter cells does not get a plastid. Here an organ has been lost through disuse, as Lamarck and Darwin taught that organs could be lost. The descendants of such a cell never become green, and starve to death even in light, unless they can get food.

It is probable that animals originated from plants on a great many occasions, generally by a sudden "leap" of this kind, and it is likely that the first animals were flagellates. But it is fairly sure that, even if animals arose separately several different times, the first animals in each pedigree consisted of single cells. The single celled animals, and others consisting of a number of cells not much differentiated, are called protozoa, or First Animals. Most of them are too small to see without a microscope. But they can build mountains and overthrow empires, so they are quite important.

THE SIMPLEST ANIMALS

The simplest animals, which are called the protozoa, consist of single cells. There are several good reasons for thinking that the first animals did so. There is no sharp gap between the single-celled animals and plants living to-day, and a very big gap between the many celled ones. Every animal except a few which reproduce by splitting or budding, starts life as a single cell. You and I did so. Since the development of an individual runs roughly parallel to the evolution of its ancestors (for example you and I had tails and hairy coats before our birth) this is an argument for a one-celled ancestor. And fossils of protozoa are found in pre-Cambrian rocks before anything but fragmentary fossils of other groups are found. They are certainly as ancient as many-celled animals, and probably more so.

The protozoa living to-day are grouped into four classes. Perhaps the most primitive class is the Flagellata, which swim about by lashing their tails. You will find them in all sorts of foul water. But you may also find them in human and animal blood. A group of them, called the trypanosomes, are one of the curses of Africa. They cause "sleeping sickness" in man, and number of diseases in animals.

Many people regard the class called Rhizopoda as even more primitive, though others think their ancestors were flagellates, for some of them have flagella when young. They include animals such as *Amoeba* which creeps about in damp soil. It is a mass of protoplasm constantly changing its shape, and lives by engulfing smaller creatures, such as bacteria, or fragments of larger ones. *Amoeba* is too small to see clearly without a micro-scope, but some other rhizopods are quite large, and build complicated

skeletons of limestone or silica. The largest were the nummulites which lived in the sea some fifty million years ago. They ran up to about the shape and size of a penny, and their skeletons have formed ranges of limestone hills.

The third class are called the sporozoa, which are all parasitic, and reproduce by very small spores. Compared with Sporozoa, tigers, wolves, and crocodiles are pleasant and harmless animals. One group of them cause the set of diseases known as malaria in man. They live in the blood, and every one, two, or three days, they burst out of the red cells where they have been growing, and swarm. This causes a violent bout of fever. I have no doubt that malaria made history on a very large scale. I don't believe that British are a superior race to Indians. But I do believe that a Briton without malaria is generally superior, particularly as a fighter, to an Indian infected with it.

Malaria is terribly common in most warm countries where mosquitoes can live. For the sporozoa concerned live in mosquitoes as well as man, and when a mosquito bites a man they can be transferred from one to the other. Socially malaria is a worse disease than plague or small-pox, because it lasts for years, and may turn most members of a population into chronic invalids. Those parts of India which are chronically infected with malaria have frequently been conquered by quite small armies from less malarious countries such as Afghanistan, Nepal, France and England. One of the main tasks of an Indian government will be to rid their country of this disease. This will be a much more efficient measure of national defence than making aerodromes or warships. Other sporozoa attack animals, and are responsible, among other things, for some of the worst diseases of rabbits and poultry.

The fourth class is called the Ciliata. They are mostly swimmers, their bodies covered with tiny structures called cilia, which beat in unison like oars projecting from a boat. They have

very definite shapes, and parts of their cells are specialised to perform functions like those of the mouths, stomachs, kidneys, and so on, of higher animals. They may even have the beginnings of a nervous system. Most of them live in dirty water, and some can just be seen with the naked eye as tiny dots. Their shapes are perhaps the most fantastic of all those which animals can take.

For one thing they are often quite asymmetrical. This is an advantage to a swimming animal which has no eyes or ears to guide it, though it has something like a sense of smell or taste which attracts it to the neighbourhood of food. A symmetrical animal swimming blind will go in a straight line or a circle, so it will either leave the favourable area quickly, or come back to where it started. An asymmetrical one moves in a corkscrew spiral and can visit most parts of a small volume of water in the course of time. Some of the ciliates spend most of their lives attached to a plant or stone, and catch their prey as it goes by. Only a few live in larger animals, and cause disease.

The protozoa usually reproduce in a very simple way. A cell eats till it has doubled its size, and then splits in two, and the new ones start afresh. Even kinds large enough to see can double their size in a day. But sometimes they have sexual reproduction, in which case two cells often fuse into one, which later divides. There is every gradation between complete union and a process like the sexual reproduction of larger animals.

We are just beginning to find out about their sexes. Only a few fall into two groups corresponding to males and females. But in some species there are several different mating types. Members of the same mating type never mate. But they can mate with members of any other type. If there happen to be just two mating types in a species we may call one males and the other females. But some species have three mating types, and others up to eight. None of the higher animals have more than two sexes. It is hard to imagine what human life would be like if we had more than two.

Certainly there would be new plots for novels. For if three protozoa are of different sexes, any two can mate. But as no protozoan mates more than once there is bound to be an odd one left out.

Sometimes a pair of cells remain stuck together after they have divided in the sense of forming a partition between them. In a few cases anything up to a hundred cells may form a "colony." If they are all alike, this is not very interesting. But occasionally some are specialised for feeding and others for reproduction. We have the very beginning of the aggregation and specialisation of cells which we find in the higher animals.

JELLYFISH AND POLYPS

You and I have one set of hollows in us communicating with the outside by the mouth. We have others which open by other orifices, and several, including the blood vessels, which do not open to the outside at all. A bee or a snail has the same relatively complicated structure, and so do many simpler animals, such as earthworms.

But the three simplest main groups of many-celled animals, or phyla, only have one set of hollow organs. Perhaps the simplest animals, and certainly some of the most ancient, are sponges. A sponge is a mass of cells traversed by small channels, which lives by filtering water through itself and catching suspended particles. A bath sponge is the skeletons of one kind. Others produce chalky or flinty skeletons which are not used by man. There are several different kinds of cells in a sponge, and some of them are extremely like one group of protozoa, so it is at least possible that the sponges are descendants of members of this group which stuck together.

The next most primitive group, apart from some microscopic parasites which may be degenerate, is called the coelenterates. They have a mouth and a stomach which communicates with different parts of their bodies. The most familiar forms to us are sea anemones and jelly fish, but the corals are much more important, as they have been in the past, and still are, builders of masses of rock.

A typical coelenterate has a number of tentacles with which it catches its prey, a mouth in the middle of them, through which it also rejects the undigested remains of its food, a body wall with muscles, and sexual organs whose products may burst through the skin or be shed through the mouth. It may be a swimmer like jellyfish, or a fixed polyp, like sea anemones and corals. More generally, it goes through both phases. An animal roughly like a sea anemone buds off

a whole series of jellyfish, mouth upwards, which swim off, grow larger, and produce eggs which give rise to tiny animals which settle down again on a rock. A jellyfish has a nervous system consisting of a network of fibres which coordinate its movements so that the whole bell contracts at once, and is often connected with "eyes" which are sensitive to light though they cannot perceive form, and an organ to enable it to keep the right end upwards.

Can we say that such a simple animal has any feelings, or anything approaching consciousness ? I don't know, but I doubt it for this reason. Our own intestines have a nervous system rather like that of a jelly fish which enables them to contract rhythmically as it does. Now if the nerves connecting our intestine to our brain are cut, we do not feel a stretching of it which would be very painful if the nerves were working normally. It is perhaps possible that there is a pain in the intestine, with no one to feel it. But unless this is so, I think it rather unlikely that a jellyfish feels pain or pleasure.

The higher animals probably evolved from coelenterates, but the coelenterates also tried a method of evolution of their own, which did not get them very far. In some species a group of animals like simplified sea anemones divide, but do not separate, and each one is specialised. So a single "colony" can consist of one animal specialised as an air bladder for floating, several for swimming by jet propulsion, others for protection, a number for eating, and finally others for breeding. They all share a common digestive tube, and between them constitute a very original sort of animal. One of these colonies has even developed a sail, by means of which it drifts before the wind. This is one of the many lines of evolution which has been tried out by several groups of animals, but has never produced an animal as integrated as a fish or a beetle.

Closely related to the coelenterates, and often included among them by classifiers, are a group called the ctenophores, or combjellies, which are now usually put in a separate phylum.

They have the beginnings of a third layer of cells between the

skin and the stomach lining, such as exist in all higher animals. They also have a pair of excretory pores apart from the mouth. Most of them are swimmers, with up to six fin-like organs which give them their names. A few species are quite common in the British seas. But the most remarkable ones have taken to crawling on the sea bottom, and begin to look like the simplest worms. What is more, their developments is rather like that of some worms, and they may possibly resemble the ancestors of worms, and hence those of higher animals. However, we do not know whether they are a primitive group, because none of them have shells or skeletons which have been fossilised. The coelenterates are certainly a very ancient group. And it is quite likely that our ancestors passed through a stage of this kind before they developed heads, limbs, hearts, and so on.

Most coelenterates have stinging cells, especially in their tentacles, which enable them to paralyse small animals which come into contact with them, and to hold them while they put the tentacles into their mouths. They stay fixed or drift about aimlessly, eating food with which they happen to come into contact. The fact that they live shows that this is a fairly successful way of life. It enables them to get along with very feeble muscles, a very simple nervous system, and very incomplete information about their surroundings. They are very much at the mercy of their environment, they cannot search for food or migrate when conditions get bad. But on the other hand they have only to make skin, stomach lining, a jelly which consists mainly of sea water, and sexual products, out of their food. Their most successful members are the corals, which live in surf where the waves are constantly bringing them fresh food. Very few of them have managed to colonise fresh water, and none live on land. In fact they are pretty incomplete animals, and just for this reason intensely interesting for the student of evolution.

WORMS

Sixty years ago zoologists classified a great variety of simple animals as worms. To-day they divide them up into about fifteen phyla, each of which is thought to be about as different from the others as say snails are different from flies or fish. Nevertheless there was some sense in the old classification. Any animal more complicated than a coelenterate has various organs between its skin and its gut. A great many of them are fairly long, with a mouth at one end but no very definite head. From these, three different groups, which mostly have heads, have evolved separately, namely the molluscs such as snails, the arthropods, such as insects, crabs, and spiders, and the vertebrates, such as fish and men. The worms represent a large number of different phyla, or main lines of evolution, which have neither developed heads, hard shells, or various other specialised structures.

The simplest worms are the Flat Worms, which have organs between the skin and gut, but no hollow ones shut off from the outside like our blood vessels, nor what is called the coelom, the body cavity in which our internal organs, such as the heart and stomach, lie. Some of them are elegant little creatures, often black, which you can find in brooks under stones and leaves. But the most successful flat worms live in other animals as parasites. They include the flukes and the tapeworms.

The flukes, such as the sheep liver fluke, still have mouths and other organs. The tapeworms are extremely degenerate. They have no mouths, but generally live in the intestines of other animals, soaking in the digested food through their skins. Both these classes generally live in two hosts at different stages of their lives. For example the sheep liver fluke hatches out in water, bores its way into a snail, multiplies there, bores its way out, and attaches itself to a

plant. If a sheep happens to eat this plant, it makes it way into the sheep's liver, and lays eggs which come out in the sheep's dung.

One of the tapeworms which infest men starts life in a pig, and only gets into the human gut if a man eats pork which has not been properly cooked. Others start life in fish. We can avoid them by seeing that our food is thoroughly cooked. Some worms have only one host, others as many as three. A tapeworm can live for years and produce many millions of eggs. On an average only one will give rise to another tapeworm, but that one has found such a favourable environment that unfortunately for us the system works. Another whole phylum of worms, the Acanthocephala, are all parasitic, but luckily they are rare in men.

A much more important phylum, the Round Worms, includes a great many free living forms which are found in soil, and are mostly too small to see clearly without a microscope. Those which eat the roots of plants are quite serious agricultural pests. But perhaps most species of round worms, and certainly the largest, are parasites. Most of us harbour one or two in our insides at one time or another in our lives, and are slightly ill in consequence.

The most formidable to man is the hook worm *Ankylostoma.* It was this animal rather than General Grant which won the American Civil War. The Negro slaves from West Africa harboured these worms. They spread if human excrement containing their eggs is left lying about, so that the larvae get out, and come into contact with the human skin. They burrow through it, and find their way into our intestines, where they suck blood and cause anaemia. The slaves had no lavatories and no boots, so they became heavily infected, as did their white masters. *Ankylostoma* needs warmth and moisture for its larvae. So the only serious outbreak in Britain occurred in the Cornish tin mines. It was at once controlled by providing the miners with proper sanitation.

A much more respectable phylum of worms is called the Nemertines. They are mostly sea animals, and about forty different

kinds live round British shores, under stones and in the mud. They are lively muscular creatures, with a threadlike proboscis which is generally kept inside out in their bodies but can be shot out after prey. They are extraordinarily thin for their length, which may be anything from about half an inch to thirty yards. In fact one of them, *Lineus marinus,* is the longest of all animals. A large whale only runs to about twenty-five yards, and the worm can probably add another five or ten with its proboscis. But it is less than an inch in girth. The nemertines need a heart to supply oxygen to their vigorous muscles, and have even got red blood, and, for worms, quite a good nervous system. I am glad to say that very few of them are parasitic, and only sorry that none of them live on land in Europe, as some do in the tropics.

I must pass over half a dozen or so small groups, each with a few dozen species at most, but so unlike as to be regarded as distinct phyla, to come to the most advanced worms, the Annelids. These are divided up into a number of segments, each segment having a structure rather like its neighbours. One can see that the skin of an ordinary earthworm is divided into rings. This division is not merely skin deep. Each segment has its own section of the body cavity, its own muscles, blood vessels, nerves, kidneys, and so on. A few segments also contain sexual organs.

The earthworms have bristles which point backwards and help it to force its way through the soil, but nothing resembling legs. However, some of the sea annelids have a pair of appendages on each segment which may be regarded as rudimentary legs, and the appendages at the front end may be modified into jaws or feelers.

Some of these worms also have eyes, so that naturalists have dignified their front ends with the name of heads. There is every gradation from a fairly hopeful head to the condition found in the earthworm. This very fact makes it clear how a head can evolve, by the concentration of jaws, eyes, feelers, and so on at the front end of the body.

The annelids include the species of worms best known in Britain, namely the earthworms, the lug worm which is used for bait, and the leeches. They also include a number of very fantastic sea animals, some of which are hairy like mice, others live in tubes of sand grains stuck together, while yet others are vigorous swimmers. An annelid worm with its many segments each with a pair of legs, its feelers, its jaws, its head, and so on, is not very unlike a centipede or a caterpillar. It is entirely probable that the insects and their relatives are descended from segmented worms. But we must wait for more fossils to prove or disprove this theory.

Another type of animal of which there are a number of phyla is the polyp, that is to say a fixed animal with a number of tentacles round its mouth, and occasionally a beak. The polyp's way of life, like that of the worm, has been adopted by animals of very different structures, some for example with hearts and gills, though mostly without. The most successful phylum of this kind, called the Polyzoa, have done their share of rock building though less than the corals.

LIVING IN ONE'S SKELETON

One reason why one regards a crab or a dog as a higher sort of animal than a snail or a starfish is that the crab and dog have jointed limbs with hard skeletons, capable of very precise movements. But there is a very big difference. The dog's skeleton is inside, the crab's outside. The group of phylum of animals which mostly have jointed limbs and external skeletons is called the Arthropods. Clearly their skeleton gives them a great deal more protection than our skin. But it has a big disadvantage. They can only grow by moulting, and are very vulnerable during the moult. The Arthropods fall into four main divisions; the Trilobites, sea animals of the general appearance of woodlice, and all extinct; the Arachnids, including spiders; the Crustacea, including lobsters, and the Progoneata, including centipedes, millipedes, and insects. Some writers include a fifth group for a strange animal called Peripatus, resembling a caterpillar which never becomes a butterfly.

An arthropod is built up of segments, some of which may be fixed, and each of which may carry a pair of appendages. The arachnids differ from the rest in having clawed appendages, instead of feelers, or antennae, on the front segment. They include such well-known creatures as spiders, scorpions and mites. They also include extinct sea animals up to six feet long, and the still living king crab, which measures a foot or so. But their queerest members are the pycnogonids, sluggish sea animals consisting almost entirely of legs attached to a mere vestige of a body. Even their digestion has to be done in the legs, and a tube extends down each leg from the stomach.

The crustaceans include a great many simple creatures like the water fleas; and some of the smaller sea forms are extremely

successful, and very important as the main food of some fish which we in turn eat. Other crustaceans have developed into the complicated shrimps, lobsters, and crabs, where some limbs have been specialised as feelers, others as jaws, as pincers, as legs, and as swimming organs. Only a little less complicated are the sandhoppers, and the woodlice, which have established a foothold on land. But some crustacea start life respectably enough, as little swimmers like water fleas, and then degenerate, becoming parasites inside other crustacea or fish, and end up as shapeless lumps. An odder fate has befallen the barnacles. They stick themselves to a rock by their front ends, and live by kicking food into their mouths with their back legs. Meanwhile they produce a shell, not of horn, but of lime, which protects them against enemies and low tides.

None of the animals so far described have definite heads. A spider or a lobster has a front part with the mouth, eyes, and legs, and a back part or abdomen. But the insects, and their relations, such as centipedes and millipedes, have a head movable apart form the segments which carry the walking legs. The insects have six walking legs, one pair of antennae, three limb pairs for mouth appendages; and may or may not have wings. The other groups included with them, such as centipedes, have more legs.

The insects are, at least as regards numbers of species, incomparably the most successful of all animal groups. This merely means that each species is generally well adapted to a particular sort of life, and to no other. So there is room for an immense number of different insect species in the same area, not competing directly with one another. And among the insects the most successful order is the beetles. At the present time nearly a million species of insects are known, at least a third of which are beetles. And these numbers are growing steadily. A naturalist recently described over 400 new species of weevils (small beetles) from a single Pacific island. As compared with this there are only about 8,000 species of mammals altogether, and only sixty in Britain.

The insects are divided into a primitive group which have no wings and whose ancestors never had them, and a group whose ancestors at least have had wings, though some, like the fleas, have lost them. The primitive ones, such as springtails and "Silverfish" are mostly small, though some play an important part in the soil.

The winged insects are not so clearly divided into those which grow up by a series of moults at which every stage is an obvious insect, and those which have larvae quite unlike the adult. Examples of those whose young are fairly like the parents are grasshoppers, cockroaches, and earwigs. Even the young of dragonflies and mayflies, which live under water, are recognisable as insect.

But no one would guess that a wasp grub, a fly maggot, a swimming mosquito larva, a "wire worm", or a caterpillar would grow up into a winged form, unless they had some knowledge of biology. The larval forms have learned to live in all sorts of environments. Thus some are burrowers. One lives underground for seventeen years, followed by a week or two as a flier. Others live in decaying wood or meat. Still others are parasites inside other insects or occasionally in mammals. But this sort of parasitism does not lead to degeneracy. The adult female of a species which grows up as a parasite in a caterpillar has to have very well developed senses to find just the right kind. She does not rely on chance, like the tapeworm, to find a host.

Still more remarkable, a parasite can evolve away from parasitism. The most primitive members of the order Hymenoptera lay their eggs in plants, where the larvae live in galls, or else in caterpillars and grubs. The next higher group catch grubs which they paralyse by stinging, and on which they lay eggs. At a later stage, some wasps feed their young with chewed up animal food. And finally the bees feed them with pollen, and with their own secretions. This development of parental care and social life from parasitism is one of the most amazing in the whole history of evolution. It may of course be compared with the evolution of

human society through slavery and class oppression to communism.

Roughly speaking the insects on land and the crustaceans in the sea fill the same kind of place, the place available for moderate -sized animals with highly developed senses, complicated instincts, and some intelligence. Luckily for us, they cannot grow very large. Imagine a cow which had moulted its whole skeleton, and was waiting to grow a new one, and you will see why. But it is perhaps mainly because of this limitation that the arthropods have not completely conquered the world.

SHELLED ANIMALS

A number of animal phyla have developed shells mostly made out of lime, and live inside them. The most successful of these phyla is the molluscs. They are fairly complicated animals, with hearts, gills or lungs, kidneys, livers, glands of internal secretion, and so on.

There are three successful classes. The gastropods, of which the snail is the best known, have what may be called a head, and typically a "foot" on which they crawl. Their shell is generally coiled, and they are the highest animals except the flat fish which are quite asymmetrical. However some of them such as the limpets, sea slugs, and the beautiful swimming snails called pteropods, have straightened out again externally, though they still keep a little asymmetry inside. The snail plan of life is a pretty successful one, for numerous snails live in fresh and salt water, and on land, and a few slugs burrow quite deep in the earth, using their small shell to push the earth aside.

The bi-valved molluscs or lamellibranchs, like the mussel and oyster, have specialised in defence, and do not move very fast, though cockles can jump and scallops can swim. They mostly live by filtering small particles out of water. They have never come out on land, and have not even colonised fresh water on a great scale.

The third great class of molluscs, the cephalopods, such as the squid and octopus, have eight or ten tentacles round their mouths, and a very definite head, with excellent eyes and other sense organs. In the past they included the very successful ammonites, which lived in coiled shells, but to-day almost all of them have internal shells which merely stiffen them, or none at all. They all live in the sea, and are probably the most intelligent of sea beasts. The octopus

has a high degree of control over its tentacles, and uses them for building a nest of stones. Among the cephalopods are the heaviest of all invertebrates, huge squids weighing many tons and measuring up to fifty feet in length, including the tentacles. But the cephalopods seem to be a dead end. For hundreds of millions of years they were among the most numerous sea animals. To-day they are comparatively rare except in the Antarctic seas.

There are two minor classes of molluscs. One has a shell divided into eight plates, and looks rather like a woodlouse. The other lives in long tubes like miniature tusks. The molluscs are handicapped for movement by their clumsy shells. A number of them, like the slug and the cuttlefish, have given them up or only kept them as stiffening. But an animal without a skeleton is handicapped too. So on the whole they have been less successful than the arthropods or vertebrates.

Another phylum called the brachiopods make bivalve shells which are pretty like those of the bivalved molluscs, though their soft parts are very different. They have made less progress than any animal group known to us. One type, *Lingula*, has evolved so little that the living shellfish are assigned to the same genus as those which lived four hundred million years ago. That is to say they do not seem to differ much more than horses and donkeys, or cats and leopards. No wonder the brachiopods are very much rarer to-day than they were in the past.

Another great phylum of animals, some of which have shells, is called the echinoderms. Some are fixed to the sea bottom, others move about slowly. The most typical members have a five-fold symmetry like a primrose or wild rose flower. The best known echinoderms are starfish and sea urchins. They are unlike all other animals in quite a number of ways. For example many of them have a system of tubes full, not of blood, but of sea water which they use for expanding hollow "tube feet" which they can force out through holes in their shells.

The sea urchins have also solved a problem which no other animal has solved, namely how to live in a box and yet to grow. The snail has one end of its box open, which it can sometimes close with a shelly door. The mussel has two valves, but these can be forced open. The tortoise is open at both ends. The sea urchin's shell consists of a number of plates which grow at their edges, but cannot be forced apart. It has a small, well protected mouth, and numerous pores through which tube feet, and muscles to move its spines, protrude.

The earliest echinoderms were probably fixed to the sea bottom. Most of the fixed types are extinct, though some still live, looking rather like plants. In fact they are called sea-lilies. In several of these the "flower" breaks off the stalk when it is fully grown, and swims away as a kind of starfish. However the ordinary starfish and urchins are never fixed, whatever their ancestors may have been. Just as in the molluscs, there is a conflict in the echinoderms between the needs for movement and protection. Some like the starfish, have a tough skin with spines, but no box. Others, like some of the sea cucumbers, have quite thin skins.

We do not yet know much about the interrelations of the main phyla of animals, largely because all except the vertebrates had already developed their special characters five hundred million years ago, when the Cambrian rocks, the first which contain many fossils, were laid down. But their development tells us something. Molluscs often start life as a swimming larva startingly like the larvae of some annelid worms. They are probably more nearly related to them than to the echinoderms or the round worms, for example.

And strangely enough, in their early development the echinoderms pass through a stage with only one plane of symmetry, not five, which is not very unlike an early vertebrate embryo. They also resemble the vertebrates in several chemical matters. If these two phyla are related, the connecting link may be a group of extinct

animals called the Machaeridia which died out three hundred million years ago, and were like echinoderms, except that they had one plane of symmetry, instead of five. Nobody, of course, suggests that our ancestors were sea urchins. But it does seem likely that one would not have to go back quite so far into the past to find the common ancestor of men and sea urchins as the common ancestor of men and bees or of men and snails.

FISH

We men belong, together with four-footed animals, birds, fish and so on, to the phylum called Vertebrates, characterised, among other things, by a many-jointed back-bone.

There are a number of groups of animals, some of which are fairly surely, others more doubtfully, related to the vertebrates. A worm called *Balanoglossus* has a rod resembling the horny rod which precedes the backbone in our development, and slits in its gullet like the gill slits of a fish. It also agrees with us and with some of the echinoderms, and differs from most other invertebrates, as regards the biochemistry of its muscles. Some zoologists take these resemblances more seriously than others. If it is a relative, so probably is a living creature called *Rhabdoplcura* which lives a life rather like a tiny sea anemone in the deep sea. And so were a large extinct group of polyps called the graptolites.

Few zoologists doubt that we are related to the tunicates or sea-squirts. When adult they are mostly fixed to rocks, sucking water in through one hole and squirting it out by another after filtering food out of it. But many of them start life as "tadpoles" resembling a vertebrate in a great many respects, and some of these tadpoles do not settle on rocks, but swim throughout their lives. Roughly speaking we may say that the tunicates are related to fish and men as barnacles are related to shrimps and bees. They have become fixed and lost many organs. We have kept moving and gained new ones.

A much nearer relative is the lancelet, *Amphioxus,* which may be described as a fish without a head. As it is also boneless the relationship is hard to prove from the fossil record. But by great good fortune a few quite ancient fossils of a boneless animal called *Jamoytius* have been preserved in shale, and are like lancelets but

with better developed eyes. So the few who doubted the relationship of *Amphioxus* to the vertebrates are now fewer.

The most primitive living vertebrates are the lampreys and their relatives. Superficially they look like eels. But they have no paired fins and no jaws. Instead they have a round mouth and horny teeth, with a number of gill slits opening out of their gullets. The most ancient fish whose skeletons we possess resembled the lampreys in having no jaws and no paired fins, but were heavily armoured. They were probably not the ancestors either of modern fish or of men. The next group of fish to appear on the fossil record had primitive jaws and were beginning to develop paired fins. Different lines of them tried one, two and three pairs of fins, and only those with two pairs have left descendants.

The fish which are alive to-day belong to many groups, but only two of them are important. The sharks and rays have skeletons of cartilage, not of true bone, and are primitive in many ways.

They have probably survived because they look after their children better than most other kinds of fish. Some, like the dogfish, lay large eggs with tough shells and plenty of yolk. Others like some rays, bear their young alive. So they produce only a few children, but these are of fair size when hatched or born, and each stands a good chance of growing up.

The more modern type of bony fish, though they are more advanced than the sharks in many ways, usually lays great numbers of small eggs. So there is a huge infantile mortality, and very few young fish live to maturity. They have however been extremely successful, largely because they can swim quicker than any invertebrates, and though most of them are much alike, some have specialised in extraordinary ways.

Several groups have taken to lying on one side, and are almost as asymmetrical as snails. It is well worth looking carefully at the

next flat fish you or your wife buy. And if you don't believe that it was evolved from a symmetrical ancestor, it is up to you to explain why it hatches out symmetrical, and then takes to lying on one side, while its eye moves round to the other. Others, like the eels, have lost, or nearly lost, their paired fins. Some have taken to living in bony boxes, often spiny, like echinoderms, and can only swim very slowly.

Those which live in the great depths of the ocean are often highly specialised. Some have luminous organs with lenses, which enable them to see in what would otherwise be utter darkness. Others which live in the middle depths a mile or so below the surface and above the bottom have immense mouths, and probably only get one or two meals a year when some dead animal falls from near the surface. One, I regret to say, lives inside a sea cucumber. This is the only example of parasitism in an adult vertebrate. But another fish, the bitterling, lays its eggs in the gills of a fresh water mussel, and is therefore a parasite when young.

There are still a few living fish which are fairly like those which went ashore in the Devonian, or Old Red Sandstone Age, and became our ancestors. They have paired fins with a bony axis which is much more like the limb of a four-footed animal than are the spiny-fanned fins of modern fish.

A great many of the bony fish have air-bladders. Some can rise to the surface to fill them and thus supplement their gills if the water gets foul. Others have closed air-bladders whose only use is to buoy them up in the water. Among the living fish which are most like our ancestors are the lung-fish of Australia and Africa, which burrow into mud when the swamps where they live dry up, and can breathe air for months on end.

Several living fish have paired fins modified for walking, either on the sea bottom, like the gurnets, or on land, like the mud skippers, and the evolution of some kind of limbs was not the

biggest problem which faced our ancestors when they came out. One of their problems was reproduction. Most female fish lay eggs in the water, the male pours sperm over them, and the eggs are left to themselves. The first land vertebrates doubtless had to go back to the water to breed, and there are still plenty of living animals such as frogs and newts, which have not yet got over this necessity.

BEASTS AND BIRDS

Life began in the water. The first land animals of which we have fossils are flightless insects, presumably descended from something like the modern crustaceans. Later, perhaps fifty million years later, fish came on land and developed legs.

Perhaps it was to get away from them that insects took to flying at the time when the coal was formed, or may be earlier. About the same time the first four-footed animals produced eggs with shells tough enough to prevent the young from drying up, yet sufficiently porous to allow oxygen to soak in. Once this was done, they did not need water to breed in, and could live anywhere on land, except perhaps in very cold regions. We speak of these early four-footed animals as reptiles, But I have little doubt that in another fifty years or so we shall use a different classification.

Like any group of animals which conquers a new habitat they specialised in all sorts of ways. One group, from which we are descended, quite early developed; the three different kinds of teeth, cutters, dog-teeth and grinders, which are found in most mammals. And they probably had hair. They seemed to be the most progressive animals. Yet they mostly disappeared, and were ousted by a group called the Archosaurs (ruling reptiles) which dominated the land for a hundred million years. Their best known members were the dinosaurs and the flying reptiles, or pterodactyls. Their living descendants are the birds and the crocodiles. A great number of them walked on their hind legs and used their fore paws for grasping. The one thing they did not do was to develop their brains.

The existing lizards and snakes are only distantly related to them, being descended from a group which was not very important during the great age of reptiles. The tortoises, which have gone in

for armour and slowness, like sea-urchins, snails, and crabs, are even more distantly related. At least seven and probably many more groups of reptiles went back to the sea, and of these the ichthyosaurs were as highly specialised as the modern whales, even bearing their young alive. Of these groups only the turtles and sea-snakes survive. Two or perhaps three groups learned to fly, of which only the birds survive. Others developed gigantic size, and some of the plant-eaters had more efficient grinding teeth than any living animal.

In fact during the time between the formation of the coal and the chalk, nature tried a vast variety of experiments with fourfooted animals. About the end of the chalk, almost all of these came to an end. We are absolutely in the dark as to why they did so. There are any number of theories, one as good —or bad —as another.

Fortunately the ancestral mammals, descended from a group of reptiles who had almost disappeared before the archosaurs, were there to take their place. There was such a vacancy for large land animals that quite a number of flightless birds, like giant toothed penguins, stepped into it. But they were soon ousted by the mammals, which have now had seventy million years to adapt themselves to various ways of life.

They have done most of the things which the reptiles did, on a higher level. Like the pterodactyls, the bats have taken to the air; like the ichthyosaurs, the whales have assumed the form of fish. The moles are more efficient burrowers than any reptiles of which we know. On the other hand the kangaroos are the best mammalian attempt at a pattern of animal resting on its hind legs and tail which was rather common among the dinosaurs. And the armadillos are not so effectively armoured as the tortoise. We mammals have not produced a form like the snakes; and though in each age there have been a few monstrous forms like the elephant and the rhinoceros, the reptiles certainly evolved more

and heavier monsters, apart from the whales.

When we think of mammals we probably think mostly of hoofed animals like the cow, deer and horse, carnivores like the lion and wolf, and animals with hands like the monkeys and ourselves. But it is striking that about half the living mammals belong to the order of Rodents, which includes rats, beavers, and porcupines. On the whole these are the most successful and wide-spread of mammals.

I think the most original mammals are whales, elephants and men. The largest whales are all filter-feeders. The largest reptiles ate plants or fairly large animals. But the great whales have no teeth. They live on shoals of shrimp-like crustaceans which they strain out of the sea with their sieves of "whalebone" which have replaced their teeth.

The elephants have developed a trunk which allows them to do at least some of the things which we do with our hands, while using all four legs for walking. If they had taken to doing something more constructive than pulling down branches with it, if for example the mammoths which lived in cold countries had started making houses to keep out the snow, they might have developed their brains as we have.

Man is rather a primitive mammal as regards structure. He has kept all his fingers and toes, and most of his teeth. He has not got a highly specialised stomach like a sheep, or a new organ like an elephant's trunk or even a cow's horns. Indeed the part of his body which is most different from the corresponding part in his nearest relatives, such as the gorilla, is probably his heel, which enables him to walk for long distances on one pair of legs.

His unique features are his very large brain and the use which he makes of it. He is not the only animal that uses tools. There is for example a bird which uses a cactus thorn to pick insects out of holes, not to mention spiders with their webs. He

is not the only animal which builds. Most birds do so. Many animals store food, and some ants domesticate other insects. But he is the only animal which deliberately shapes tools, and the only one which uses fire. Nevertheless he was a fairly rare animal till quite recently, and it is only in the last twenty thousand years that he has lived in societies bigger than large families.

As men learned to co-operate, a whole series of new problems arose, and men without ceasing to be animals passed out of the sphere of the science of zoology, just as living things, without ceasing to be material, passed out of the sphere of the science of chemistry.

WHY STEAL BEETLES?

An entomologist has recently been sent to prison for stealing beetles from the British Museum. I do not know whether he stole them because he liked them or because he intended to sell them. The value of those stolen was said to be several hundred pounds.

One may well ask why beetles should be valuable. Some sorts are regrettably common. But there is always one particular beetle, even of the commonest kind, which is specially precious. This is the type specimen, on which the person who first described the species based his description, and it generally exists in some museum or other. The zoologist who named the species may not have given a very accurate account of it. But provided the type is available, and undamaged, others can give a better one. Why does this matter? Why is it any more important than the description of a kind of postage stamp?

The reason is this. If we know to what species an animal belongs, we may know a great deal about it. It is important to know whether a beetle is a scavenger or eats wood, crop plants, or something else of value. Even if it can eat potato plants it is not a menace to British agriculture if it belongs to a tropical species whose members are killed by a mild frost.

Of course within a species there may be several geographical races differing in their resistance to cold, and what is more striking, in thirty years or so a race may arise which can eat a new food plant.

Nevertheless most species are pretty well adapted to one sort of environment, and find it rather hard to live in another one. This is particularly true of beetles. We do not know how many

species of beetles there are. But there are certainly more than four hundred thousand. That is to say something like a third of all the known species of animals are beetles. However, beetles are not enormously more successful than other insects. The total number of individuals of Collembola, a group of insects which one can hardly see without a lens, is probably much greater than that of beetles. The reason why there are so many beetles is probably that they tend to be specialists, for example eating only a particular fungus which they find under the bark of a particular kind of tree.

Now the distinction between species is made on the basis of characters such as the number of bristles on their legs, which have no obvious importance. They are important because they enable us to assign an animal to the correct species, just as the details of my face are important because they enable people to recognise me.

Taxonomy, that is to say the assignment of animals to species and of species to genera, families, and so on, is only a part of zoology, but is an important part. Darwin called his greatest book *The Origin of Species*, and he knew what he was talking about, because he had spent eight years in classifying living and fossil barnacles.

Since Darwin's time we have learned a very great deal about another aspect of evolution, namely the slow changes by which, for example, the descendants of three-toed short-toothed animals have become horses with only one toe per leg, and long teeth suited for chewing grass. We can learn about this from fossils. But fossils do not tell us anything about the kind of difference which exists between a horse and a donkey, and causes the hybrids between them, the mule and jennet, to be sterile. This is a very important difference, and we can only learn about it by studying living species, and geographical races, which seem sometimes to be species in the making, because they may give sterile or weakly hybrids.

There has been a natural, but unfortunate, tendency to confine taxonomy to museums, so that university students learned

very little about it. London University has just appointed a reader in taxonomy to combat this tendency. I do not envy him his job. He too will need a large collection of beetles or whatever small animals he may use, for our university has neither the space nor the money for a collection of animals as large as deer or even birds. He will have to teach students how to distinguish different species, and how to decide whether an animal belongs to a new species previously undescribed. And no doubt he will explain that the needs of a species, as shown by the food which it eats and the climates in which it can live, are even more important that the characters used for describing it.

The practical importance of such work can be judged by a simple fact. The Government has great schemes for growing groundnuts and sunflowers in tropical Africa. It is quite useless to grow a plant which needs insects such as bees to fertilize its flowers in an area where there are not enough of the necessary insects. It is equally useless to do so where there are insects which will devour the crop. I do not know whether there has been an adequate survey of the insects in the African areas concerned. If not, the whole scheme may fail for this simple reason. It may seem ridiculous that the measurement of bees' tongues under a microscope could decide whether sunflowers can or cannot be grown profitably in a particular area. I hope it did not seem ridiculous to the people responsible for these schemes. If it did, the results may be pretty serious. A vast amount of public money will have been wasted, and we shall have less margarine in 1950. But this simple example shows that a collection of insects has a use value as well as a rarity value like postage stamps.

Of course the majority of insects have no economic importance, and are not likely to have one. But you do not know this beforehand. It would be short-sighted and impracticable to try to ignore animals not known to be of economic importance. Darwin's barnacles are a good example. If we knew how to stop barnacles growing on ships' bottoms we could save a vast amount of coal

and oil. Among the things which Darwin discovered in barnacles was the apparatus by which they cement themselves on to rocks or ships. Certain kinds of paint make it harder for barnacles to do so. But none of them is fully efficient. It may need a man with Darwin's powers of observation and insight to solve the problem completely. The novelist Lytton Bulwer satirised Darwin for his interest in barnacles. To-day Dr. C.D. Darlington thinks that too much of the national income is being spent on taxonomy, especially at Kew.

Taxonomists can of course become narrow and unduly academic. So can scientists of other kinds. But taxonomy is of great practical and theoretical importance, and the beetles in the British Museum are a really valuable national property.

CAGE BIRDS

I have just been to the annual Cage Bird Show in London. Some people at once object to such a show because it is cruel to put birds in cages. This is certainly true for migratory birds such as swallows, and probably for birds which go in for long and high flights, such as falcons or skylarks. And certainly exhibition cages are rather small. But the two most popular species, the canary and budgerigar, are very tame, and often do not fly away when they are given the chance. Neither would live very long in England if it did.

I went to the show mainly as a teacher, because a lot is known about the inheritance of characters in the budgerigar, and a good deal in other species, and because the characters bred for are quite superficial compared with those, say of milk or beef cattle, so that one can easily show them to a student. I write about it here, because most breeders of cage birds are workers, and I hope that as hours are shortened and more houses are built, more and more workers will keep some sort of pet animals, if only for the sake of their children.

The budgerigar is one of the most interesting domestic animals, because we know its history. It lives wild in north Australia, and the first live ones were brought to Europe in 1840. They were light green, and since then a great many other colours have turned up. There are many shades of blue, yellows, greys, and whites, as well as light green, dark green, and olive. Also there are various combinations of these colours, such as greens with yellow head and wings, and variations in the pattern of stripes on the neck. So far there have been no important changes in structure, such as are found in pigeons, for example the pouter with its expand chest, the fairy swallow with its feathered legs, or the fantail, whose name needs no explanation. A crested form is said to exist on the

continent, but was not on show in London.

In other birds the breeds are generally kept sharply separate. Indeed the pigeon fanciers' association have very remarkable names such as the Oriental Frill Club, and the Bald and Beard Club. But the budgerigar fanciers know enough genetics not to be afraid of crossing their breeds. They know for example that if their strain of mauves is getting rather weak they can outcross to the wild coloured light green, giving dark green young, and that if these are crossed to mauve about half the chickens will be mauve. Moreover, these new mauves are likely to be invigorated as the result of the outcross. The fanciers call this sort of mating "dipping into the green".

The canary fanciers, on the other hand, have a number of different races, such as the Norwhich, Yorkshire, Border, and so on, which they try to keep "pure", though each race has several different colours. However there is one exception to this rather Nazi practice. If you mate a crested canary with a plain-headed one, you get about equal numbers of crested and plain chicks. If you mate two crested together you probably get more crested than plain among the chicks which live, but a large number of your chicks die before hatching. There is no way of getting crested canaries which breed true, and in practice they are outcrossed to specially bred consorts. Several characters in mice and poultry behave in the same way.

I wonder how many of the inborn human characters which we regard as desirable show this type of inheritance. Nobody knows, but it is far from sure that even if a dictator had absolute power to decide who should have children by whom, he would get the best results from his point of view by mating like and like.

Animal breeding may have two distinct objects; to produce better animals, or at least animals which will fetch a high price or win prizes; and to increase knowledge. The fancier cannot be of great help to the farmer who breeds animals as producers of food or wool, for a very simple reason. The farmer wants forty cows all of

which are good milkers. The fancier may breed forty canaries, and if one of them wins a national challenge trophy he does not much mind if the other thirty-nine are second-rate birds. His aims are quite different to the practical farmer's. But the fancier can advance science, and in this way he can help agriculture indirectly. For example the principles of sex-linkage were discovered in canaries before poultry, but they have been of great value to poultry breeders.

A group of cage bird breeders might quite well decide that it was as interesting to breed for knowledge as for silver cups. If they did so there is a very great deal that they could find out. There is plenty to be discovered about inheritance in budgerigars, but far more in canaries. And we know almost nothing about the various kinds of hybrids between canaries and related birds, such as linnets, goldfinches, and green-finches. We know for example that such crosses produce about ten times as many cocks as hens, and that some of the hens look much more like canaries than any of the cocks. We know that most if not all of these hybrids are sterile. But we don't know why in any detail.

We know that some budgerigars can talk. One which was shown produces the remarkable sentence "Johny Stockdale, Rooks Hill, Welwyn Garden City", which would be very useful if he were lost. But we do not know if the ability to talk is inherited, let alone how it is inherited.

Plenty of amateurs have made real contributions to science, particularly to archaeology, geology, and meteorology. Bird fanciers could do so. One essential is to record all your animals, not only those which come up to some standard. Another is to breed fairly large numbers, because many of the laws of inheritance are numerical. This means that co-operation is essential. But as a knowledge of science is spread among the people of this country, more and more should be interested in advancing it and willing to work together to do so. Few people could make more solid contributions to science in their spare time than the breeders of cage birds.

SOME QUEER BEASTS

I visit the London Zoo fairly constantly, but I suppose my taste in animals is rather different from most readers'. Still they may be interested in a scientist's tastes, even if they don't share them.

If I had to pick the most striking animal on show, I think my vote would go to a small fish called the mud-skipper. It lives in tropical mangrove swamps, and spends most of its time out of the water. At any rate those in the Zoo aquarium do so. The mud-skipper has fins, but at least one pair of them have a joint like an ankle, which enables it to use them for a clumsy kind of hopping on land. Its eyes bulge out of its head, and even move up and down like a frog's. Have you ever watched a frog eating? It has no complete roof to its mouth, so its eyes move up and down when it eats. In fact it uses its eyes to help it to push food down its throat.

I like the mud-skipper because he is trying to do what our ancestors did when they came out of the water in Devonian times. He is obviously a fish, and some of his near relatives are quite typical fish. But he has turned one pair of fins into passable limbs. He gives one an idea of what the first ancestors of the land vertebrates were like. If any critics of evolution think that fish could not have come out of water and become amphibians, you can show them the mud-skipper. Fortunately for him, he does not know that he is about three hundred million years late in his attempts to colonise the land from the water.

A fish which is interesting from a very different point of view is the Cichild from the lake of Galilee. Not only is it almost certainly a fish of one of the kinds which the twelve apostles caught, but it was probably involved in a miracle. These fish have a remarkable breeding habits. A pair of them scoop a hole in which the female

lays her eggs. The male picks them up, and carries them round in his mouth for a week or more until some time after they have hatched. As these fish also generally use their mouths to remove stones from the hole where the eggs are laid, they would be quite likely to pick up a small coin if one were lying on the bottom. Now on one occasion the apostles are reported to have had no money to pay a tax, and to have got it by hooking a fish with a "penny" in its mouth. It seems likely that this fish was caught while making a nest.

My favourite house at the Zoo is what is called the Temporary Rodent House. It contains a number of rodents, which surpass all the other seventeen living orders of mammals both in numbers of individuals and of species. I should explain that the class of mammals, that is to say warm-blooded hairy animals which suckle their young, is divided into thirty-two orders, such as elephants, whales and porpoises, bats, and carnivores, which include cats, dogs, bears, weasels and so on. Fourteen of these orders are extinct.

But this house contains representatives of three orders which are not generally known. The hyrax looks rather like a guinea pig until you look at its feet carefully, or better, dissect it. It then turns out to be nearer to hoofed animals such as pigs. Actually it is fairly like the ancestral forms of many different mammalian orders about the time when the last of the chalk was being formed. But it has evolved much less than most of the others.

Then there are the sloth and the tree ant-eater, representing the order called Xenarthra, or edentates, which originated in South America and of which a few members have got to Central and North America. This order also includes armadillos, and used to include giant sloths about as large as elephants, and armadillos six feet long. The ant-eater has no teeth at all, the sloth has very few and simple ones, and a very much worse temperature control than most mammals.

Finally there is the South African aardvark, the sole survivor of an order called the Tubulidentata. It has a nose like a pig's, ears

like a rabbit's, and is possibly the champion digger of the world. It not only lives in a burrow, but gets its food by excavating white ants' nests. Whereas the mole chooses soft earth in which to hunt worms, the aardvark works in hard and dry soil, and does it very well. If its den had not got a stout cement floor, it would be out of sight in a few minutes.

The same house contains several galagos, which are small lemurs not unlike one of the forms ancestral to men and monkeys. Unfortunately they do not like light, and to see them at their best you must visit the Zoo at night, which will not be possible till we have more coal. But in the night time they are astonishingly active and graceful.

Naturally I don't expect other readers to share my tastes. I like to see a set of animals which illustrate the various possibilities of evolution, some of which have only rarely been taken. Of course some of the invertebrates have done much odder things, for example the hermit crabs which live in coiled shells, and have their bellies bent sideways to fit them, or the barnacles, which start life swimming about like little shrimps, and then glue their heads onto rocks and live by kicking food into their mouths with their back legs.

Every mode of life has its corresponding structure, and palaeontologists have a big task in trying to puzzle out how extinct animals lived from a study of their bones and teeth. On the whole they are pretty successful, but in one or two cases it is very hard to see how the animal worked. Perhaps it had some soft part of which we know nothing, like the chameleon's tongue, which he can shoot out for a foot or so to catch flies.

Some vocations are equally queer. If you haven't seen an aardvark you may find it hard to believe that there is such a beast. And if we didn't know there were such people as stock-brokers and tick-tack men we might not credit their existence either. Perhaps both may become extinct within a comparatively short time, I even venture to hope within my own lifetime. After all we manage

without druids, rain-makers, augurs, exorcists, and quite a number of other professions which have been considered important enough in the past. It might be worth while keeping a few members of these professions if they were as odd looking as ant- eaters or mud-skippers. But their lives have not modified their structure. So let them go, provided we can keep the aardvark.

COUNTING WILD ANIMALS

One of the first things we want to know if we are to make natural history scientific is how many animals of a particular kind there are in a certain area. We also need such knowledge if we are to use our land scientifically.

In a few cases the counting is fairly straightforward. If one wanted to know how many mussels there were between tidemarks on a particular beach it would be hopeless to count them all. But it would be quite easy to take a wire square covering just one square yard and throw it down on a hundred different spots, counting the mussels in each square. This "Gallup poll", with a measurement of the total area, would give the total number within ten per cent or so.

It is obviously much harder to count animals which move about. Here again the sampling method may be quite useful with slowly moving animals like earthworms or beetles. One can dig up a square yard of meadow, and count all the earthworms in the turf and the soil beneath it, or in a fair sample of them. The results of such counts are very surprising. Not one person in ten has even seen the commonest British insects, the Collembola, which are wingless subterranean creatures about a millimetre long when fully grown, and whose numbers run up to four hundred million per acre.

It is not so easy to count more mobile animals, though curiously enough the exception proves the rule. Birds are the most mobile animals, but are easy to count in spring, because we can count their nests. For example, there are about 30,500 breeding pairs of rooks in an area of 910 square miles of the Upper Thames Valley, 4,000 pairs of herons in the whole of England, and a hundred thousand million birds in the whole world. This number may well be out by a factor or two or three, but not much more.

It is much more difficult to count mobile animals such as

flies or fish which have no definite nesting places, or whose nesting places are not easily discovered. Suppose we want to count all the field mice in a meadow, we might put down traps till we had caught them all, but before we had done so others would have moved into the vacant territory from outside. The only satisfactory method is to mark the animals. Field mice are best marked with a numbered nickel band round a hind leg, butterflies with a spot of coloured paint on one wing, fish with a leaden button at the base of one fin, and so on.

To count field mice, Hacker and Pearson put down six traps provided with food and bedding in every hundred yard square of an area of woodland. Each mouse was labelled at its first catch, and the fact that the same mouse was often caught several times a mouth made it clear that almost all the adult mice were caught at least once in a period of six months or so.

To count tsetse files in Africa Jackson invented a rather different method which is however best illustrated by the work of Dowdeswell, Ford and Fisher, who counted all the Common Blue butterflies on the island of Tean in the Scillies. On each fine day they caught anything up to sixty butterflies, released them after marking, and saw how many of these they caught next day. Thus on one day they caught 52 butterflies and marked them all. Next day they caught 50, of which 14 had been marked the day before. That is to say 28 per cent of the catch were marked. So if there had been no deaths or hatchings in the twenty-four hours, the total population was such that 52 was 28 per cent of it. In fact there were about 186 butterflies on the island.

They could thus count the population on different days, and also by seeing how the proportion of marked insects fell off, discover the average length of life of a butterfly after it has come out of its chrysalis. No marked butterflies flew to the nearest island, about 300 yards away, so their problem was much simpler than Jackson's with his tsetse flies. Here it is necessary to find out how far a fly can move during its lifetime, and this distance may be several miles.

There may be about ten thousand of these flies in a square mile of African bush. And as they can infect men with sleeping sickness and cattle with the fatal disease called nagana, it is very important to wipe them out.

A great many methods are being tried. They can be kept down to some extent by burning grass and bushes, and by killing off the deer, zebras and other animals on whose blood they live. Even trapping reduces their numbers slightly.

However, the most hopeful methods seem to involve the new insecticide D.D.T. In the South African Union there is an isolated area infected with tsetse near the coast of Zululand. This is being treated with D.D.T. smoke from aeroplanes over most of its extent, and from smoke candles in valleys where planes cannot penetrate. In other areas the cattle are being sprayed with D.D.T. so that the flies which settle on them die. However, unless not merely ninety nine per cent of the flies, but all of them, are killed, these methods will be of little use. If half measures are adopted for some months, a race of tsetse resistant to D.D.T. is quite likely to evolve by natural selection, as a race of scale insects resistant to hydrogen cyanide has arisen in the Californian orange trees.

For some purposes it is important to count the minimum number of breeding animals in the course of a year. When this gets small, the frequency of a character in the population may change by mere chance, quite apart from natural selection. Dubinin, who first demonstrated this, called this change by a Russian phrase translated as the genetico-automatic process. I am afraid I may be accused of bourgeois prejudice, but I prefer the shorter term "drift" used by the American, Wright, who produced the theory of it, but actually observed it later than Dubinin. To measure drift we have not merely to catch thousands of animals, of one species, but to classify them according to their colour, shapes and so on, and to breed from at least some of them. And we have to repeat this in a number of seasons, to see if there is a steady evolutionary change, or only a random one. In fact counting wild animals is a whole time job.

WHY I ADMIRE FROGS

Frogs are beginning to spawn in the ditches of southern England. If we get a spell of frosty weather, as we well may, they and their eggs are going to suffer heavy casualties. I shall be sorry if they do, for I like frogs. Under the general term frogs I include all the tailless four-legged amphibians. In England we only have three native species, the common frog, the common toad, and the natterjack toad. But in other countries there are plenty of animals obviously related to our frogs and toads, but no closer to one than to the other.

The frogs in this broad sense are one of the three living orders of amphibians. The others are the tailed amphibians such as newts and salamanders, and the legless, tailless, and generally blind tropical amphibians which live underground and lead a life rather like our earthworm. Within the amphibians the frogs have developed in some ways as men have done among the mammals. They have lost their tails, their hind legs are a lot bigger than their front legs, and their heads are relatively large. Of course they have not developed their brains as we have, and though they use their hands for clasping, and sometimes for climbing, they are not organs of skilled work, as the beak of a nest-building bird is.

Our frogs are limited by the fact that their eggs must be laid in water, and they pass their first few months as tadpoles. This means that they can never go very far from stagnant or slowly flowing water. Others have got over the handicap in various ways. Many frogs in South American forests spend their whole life in trees, and lay their eggs in the water which accumulates between the stems and leaf-sheaths of plants which grow on the tree bark. In countries where there is daily rain in the breeding season eggs are

often laid out of water. Several tropical frogs make nests, usually by sticking leaves together, in which a mass of eggs are placed. Sometimes these are placed actually hanging over a stream or pool, so that as the tadpoles hatch, they drop into the water. Others are placed so near to water that the tadpoles have not far to wriggle.

Quite a number of frogs burrow into the ground, including one species which is quite common in France. In one Japanese species a pair burrow into the bank of a pond above water level, seal up the entrance to their hole, fill it with eggs, and then make a tunnel opening under the water through which they leave, and the tadpoles follow them on hatching. In many cases where eggs are laid out of water the parents spend many hours kicking the egg mass with their hind legs until they have made enough froth to provide the air needed by the eggs during development. Other frogs carry the eggs about with them. The male "midwife toad" which is found in France, carefully collects the string of eggs laid by his mate and carries them wrapped round his hind legs till they are ready to hatch.

Only one frog, a West African species, bears living young. This enables it to live on damp mountain sides at some distance from water. But several species do something even odder. The female lays the eggs into a pouch covering her back, and here they develop, receiving nourishment from the mother like embryos in the womb of a mammal.

However, the queerest habits of all are those of a Chilean frog, *Rhynoderma darwinii.* Here the eggs are laid on the ground. Soon afterwards a number of males surround a mass of eggs, watch them for a fortnight or so till the tadpoles are beginning to wriggle, and then eat them, one by one. However, they do not pass into their stomachs. Many male frogs have a bladder under the skin on each side of their neck, or rather where the neck would be if they had one. This can be filled with air, and is used for croaking. It is very small in our common frog, but fairly large in the edible frogs which exist in several parts of England, and are much noisier than the

common ones. In *Rhynoderma* the tadpoles swallowed by the males are passed into the croak sacs, which enlarge enormously. When they hatch, the croak sacs produce a sticky secretion which plays the part of milk. They remain there, growing till their legs have developed. Finally the male, apparently with considerable difficulty, forces them out of his mouth, and they start life on land. I do not know how long it takes before he is able to use his sacs for croaking again. Perhaps the oddest feature in the whole situation is that the little frogs inside a male are not necessarily even his own children. It is queer enough, if you find a frog with young ones inside it, to discover that it is a male, still queerer to find that it may not be their father. Several fish species behave in a similar way. The male holds the eggs in his mouth, sometimes for several weeks, until the little fish can live an independent life.

I have not given anything like a complete account of the ways in which frogs have overcome the handicap of having to breed in water while living mainly on land. But I think I have given some idea of their variety.

Britain is very badly off for frogs and toads. We have only three native and one or two introduced species, as compared, for example, with fourteen species in France. The reason is that they find migration very hard. Not only are they killed by salt water, but a fairly dry range of hills, such as the chalk downs, is a barrier which they can hardly pass. A foreign species has recently colonised Romney Marshes, in Kent, but unless some human being helps them, it may be centuries before one crosses the hills and gets into another river basin.

I should like to see several foreign species established in England, notably the midwife toad and the spade-footed burrowing frog. They live in climates not unlike ours on the continent, and I have very little doubt that they could thrive in England or Scotland. But I doubt if it would be right to let them loose. When a foreign animal is introduced into a country it may die out. But if it does

not, it often becomes a pest.

The reason is that it has been taken away from its natural enemies. For example in many parts of Europe storks do a great deal to keep the numbers of frogs down, and we have no storks. A foreign species may also wipe out a native one, either by direct competition, or by introducing disease. This is one way in which the human races compete. For example measles, introduced by European, killed off huge numbers of natives of the Pacific Islands. But yellow fever, to which West African are fairly resistant, has prevented Europeans from colonising West Africa as they have colonised Brazil, which has a fairly similar climate.

We have no body of experts which undertakes the biological planning of Britain, comparable with the vast organisation which is planning the afforestation of the South Russian steppes. Until we have an institution which will consider the effect of any introduction on our agriculture, fisheries, river conservation, bee-keeping, and so on, it is better not to add new animals to our rather small list. Nevertheless I should like to see some of the beautiful tree frogs introduced into warm valleys in Devon and Cornwall, where they would probably do well, and several larger frogs and toads would be a delightful addition to our countryside, provided they did not kill off native animals.

THE HUNGARIAN INVASION

No, this is not another accusation against the Hungarian Government. It is an account of the successful occupation of a part of England by Hungarian frogs.

Until recently, the animals of England included two species of frog, and two of toad. The common frog, *Rana temporaria,* is found all over the country. The edible frog, *Rana esculents,* is not so common, and has very likely been introduced, either by monks, epicures or amateur naturalists. It has a patchy distribution. The nearest colony to London stretches from Richmond Park across the Thames to Teddington, though the frogs are only common at a few points in this area. There used to be a colony in Kentish Town. All the other areas where it is found, so far as I know, are in South-eastern England. These frogs are rather larger and more striped than the ordinary kind, and the males have vocal sacs behind their jaws which bulge out to a surprising extent while croaking in the breeding season.

The common toad is found everywhere, but the natterjack toad has a patchier distribution. It is particularly fond of sand-hills near the coast, and one of the places where one can be sure of finding it is near Southport and Ainsdale in Lancashire. There is no suggestion that it was introduced by human beings.

Professor A.V. Hill, the physiologist, who was a Conservative M.P. in the last Parliament, used to import frogs of the species *Rana ridibunda* from Hungary. They are much larger even than the edible frog and some of them have a very bright green colour. He used these frogs, or rather their legs, for very accurate work on the physiology of nerve. The nerves of a warm-blooded animal die very rapidly after its death. Those of a frog continue to conduct for hours

or even days after removal if they are kept moist. Among the things which Hill measured was the extremely small amount of heat produced when an impulse passes down a nerve fibre. As it would take several million nervous impulses to raise the temperature of a nerve by one degree, the measurements, have to be pretty accurate.

About 1936 he gave several pairs of these frogs to Mr. E.P. Smith, also a Conservative M.P., and dramatist, who has a house with a pond near the Royal Military Canal, which runs between Romney Marshes and the rest of Kent. The Hungarian frogs bred in this pond, and after a few years some of them got as far as the canal. They spread along it in both directions, and during the war they occupied most of Romney Marshes.

They are not only larger than the common frog, but more aquatic. They spend most of their time in the water, and when they come out they usually stay near it and jump back when frightened. They seem to have killed off the ordinary frogs and toads in the marshes, or at least reduced their numbers considerably, whether by competition or more probably by eating their tadpoles.

Their most striking characteristic is their voice, which is extremely loud, at any rate in the breeding seasons. They are the form found in Greece and which provided the chorus for Aristophanes' play "The Frogs", which is well known in Murray's English translation. According to Aristophanes they made two noises, which are transliterated, "Brekekekex" and "Koax, Koax." The Brekekekex sound, which they make during the day-time, has been compared with that of a machine gun, the Koax with the noise made by a cat when you tread on its tail. To some listeners the "song" sounds much more like Brekekekesh Koash. It is probable that the Athenians pronounced the letter Xi, which we render as X, much more like SH.

I suggest that the Classical Association, which is interested in how ancient Greek was actually pronounced, should send down a party to Appledore next May, when the frogs are breeding, to

determine this point. Our knowledge on such doubtful matters rests partly on the transliteration of Sanskrit words. Sanskrit is handed down orally, and great care is exercised to pronounce it properly in religious rites. Frogs are probably even more conservative than Hindus in their pronunciation. Some of the Marshmen find the frogs' song objectionable, and I should like to be able to use it as political propaganda, were it not that several naturalists who have been to the marshes think their complaints are exaggerated.

It is rather unlikely that these frogs will spread up the hill into the rest of Kent, and invade England. But they could colonise other marshy regions, and will do so if anyone transports them there. In 1939 Professor Hill dumped about fifty of these frogs into the Cam near Cambridge, but they seem to have died out. This is probably because when put in a river they scattered to such an extent that no male could find a female in the spring of 1940. If he had put them in an isolated pond some would probably have stayed and bred there, and they would have spread into their stagnant water and established themselves.

In captivity they will mate with the edible frogs and produce tadpoles, but no one knows whether or not the hybrids are fertile. Dr. Malcolm Smith, of the Natural History Museum, who recently described the Romney Marsh colony to the Zoological Society, hopes to test the fertility of the hybrids in a few years. At any rate *Rana ridibunda* and *Rana esculenta* inhabit different areas, and where these overlap, as in parts of France and Germany, they seem to keep fairly distinct. So it looks as if we had got a new English wild animal.

A GREAT EVENT

What was the most important event in 1944? Some would say the landing in Normandy, the break-through at Avranches, or the liberation of Paris. Others would think that some of the great victories of the Red Army, in which more Germans were put out of action than in France, were even more important.

There is, however, a third point of view. According to the London Bird Report for 1944 "The outstanding event of the year was undoubtedly the nesting of the Little Ringed Plover at a gravel-pit in Middlesex." Only once before has this species been found breeding in Britain, and it has not been seen near London since 1864. I confess I do not take the colonization of this country by birds quite so seriously as does the editor of the *London Naturalist,* but if human society had developed a little differently this event might have been of the highest political importance.

For among many primitive people rare birds are of great economic value. Wallace's account, in his *Travels on the Amazon and Rio Negro,* of the Uaupe Indians in Columbia is a classic. They kept large numbers of birds, including parrots which were allowed to fly about freely, but returned to be fed, egrets, and eagles which were kept in large houses, and ate two fowls a day. They bred these birds for the sake of their feathers, which were used for men's head-dresses. The parrots' feathers were not of the natural colour, but prepared by pulling out a green feather and then rubbing in the secretion from a toad's skin. The new feathers which grew after this treatment were yellow.

A well-dressed middle aged man also wore cords of monkey's hair down his back, a bead necklace, a large white cylindrical stone, a belt of jaguar's teeth, a pair of garters, and rattles

on his ankles. The ladies wore garters only. A powerful chief was said to be the possessor of great wealth in the form of feathers and jaguar teeth, which he had won in a series of wars, but would not show to white men, for fear of losing them. These wars, wrote wallace "are fought for the sake of their weapons and ornaments, and for revenge of any injury, real or imaginary." Wallace wrote in 1853, and had certainly not read Marx, but he made a very sound analysis of the economic causes of war.

In our own culture we do not greatly value animal products, though some furs are fairly expensive. But quite small quantities of a yellow metal, gold, and a sparkling stone, diamond, are valued at as much as a lifetime of hard work. We fight wars, for example the Boer War, for such objects, and when we have got them we shut them up in underground vaults. If we valued rare bird feathers as we do gold, the appearance of the Little Ringed Plover in England might have precipitated a Feather Rush, like Charlie Chaplin's Gold Rush. Or if it had happened a little earlier it might have decided Hitler to invade Britain rather than the Soviet Union. Actually this bird is common enough in Europe, but its introduction into a new country might well have been a menace to monopolists on the continent.

From the strictly scientific point of view the interest of such observation as this is rather slight. Indeed the fact that a rare bird is seen in England is more important to continental than to British Zoologists. Was there an excessive number of these birds in France in 1944? Or did their food run short? Was their advent connected with the much larger invasion of Waxwings which took place in the same year? Such are some of the questions which a zoologists might ask, and whose answer would help us to understand the laws governing animal population.

On the whole I am glad that rare animals do not have a great commercial value. If so their habitats would be kept secret, as are the details of the geology of oil fields, and the study of geographical distribution would be even harder than it is now. Certainly some of

the habitats are unexpected. Thus *Pseudosinella religiosa,* a microscopic insect belonging to the order *Collembola,* has only been found in the crypt of Lund Cathedral in Sweden. This crypt, by the way is interesting to entomologists for another reason. It is embellished with the carving of a louse about a foot long, sucking the blood of a lamb of the same size. The louse represents the State, and the lamb the Church, though some people have taken the parable the other way round.

But the habitat of one particularly rare and interesting animal is absolutely unknown. The late Major-General Hearsay (he really was called that) made a collection of insects which passed to the British Museum on his death. While fording a river during a battle in India he was observed to catch several specimens which he pinned to his pith helmet and catalogued later. Most of his trophies were quite common, and of no value, as he rarely stated where he got them. But one, an insect called *Prophalangopsis obscura*, is of extraordinary interest. Not only is it the only known member of its species, but the species is so unlike all other insects that it has been put in a family of its own. And it combines so many primitive characters that it is regarded as closely resembling the common ancestor of the crickets, the long-horned grasshoppers, and several other groups. Unfortunately the major-general's service was so varied that we do not know even in which continent he found it.

But my favourite story is of the Peruvian gentleman who was disturbed by a noise in his garden one night in the middle of Lima. He fired his revolver at it, and next morning discovered the corpse of a large animal unknown to science, something like a guinea-pig with a bushy tail, which was called *Dinomys,* and also assigned to a new family. A number more of these animals have since been found. We are not, however, told whether this was the most important event of its year in Peruvian history.

THE ROBIN

Most original scientific work is published in special journals, such as the *Proceedings of the Royal Society*, the *Journal of Physiology*, the *Observatory*, or the *Philosophical Magazine*. Occasionally it is published in book form, but most scientific books are summaries of work by many authors, which has already been published in periodicals.

The vast majority of papers or books containing original research are quite unreadable by the general public, because they assume so much special knowledge. A bright exception is David Lack's *The Life of the Robin,** which describes the author's researches on a subject with which everyone is familiar. It should be in every school and public library not only because of its intrinsic interest, but because it gives an easily followed account of some scientific research, a human activity which, whether or not we understand it, is of great social importance. Lack studied the robins in about 20 acres of Devonshire. The first thing to do was to catch them all, and let them out again with coloured rings on their legs for identification. His area held from 11 to19 adult robins.

Why does a robin sing? The song has been interpreted as courting, and as a sheer expression of joy. Actually both the song and the display of the red breast seems to be a substitute for fighting. One of the fundamental facts in robin life, as in that of many other birds, is territory.

In autumn every male robin occupies a territory of about an acre, in which he spends most of his time, though he occasionally feeds outside it. Within this area he sings and struts vigorously. If

* F.H.&C. Witberby Ltd., London 7/6

another male appears in it he sings at him violently, and may peck him. Usually the intruder goes off; occasionally he may fight the quarrel out, or sing it out, and occupy all or part of his rival's territory. About the new year females arrive in the male's territory, and may or may not stay there. There is a great deal of singing, which may serve to attract the females, but the females have an absolutely free choice of mates. One of the visiting females settles down with a male in his territory.

After marriage the female helps the male to defend their joint territory. But they do not mate till March or April when the nest is at least partly built. At this time the male also brings his wife presents of food, and later helps to feed his children. Occasionally a female leaves her husband for another male, and two cases of bigamy have been reported; but as a general rule a couple keep together till the young have left the nest. However during the late summer and autumn the sexes separate, and the hen usually finds a new mate next winter. The males generally stay in one place for life, but most of the females migrate, some of them passing the winter in France. In fact the male robin is the home-lover, and the female wanders about and chooses her mate.

Why do robins behave as they do? Lack did a number of most interesting experiments with stuffed birds. Both males and females will threaten stuffed specimens placed in their territory, and may attack them. If they cannot destroy the "enemy" they will desert their nest if it does not contain young. What is more remarkable, they rarely attack a stuffed robin whose breast has been dyed brown, but will threaten a small bundle of red breast feathers. It is useless to say that a robin has poor eyesight. They can recognize their own mates. Such conduct certainly seems irrational to us. But if an intelligent robin discovered that human beings spend immense amounts of energy and thousands of lives in digging a yellow metal out of a series of holes in South Africa to bury it in another hole in the United States, they might not think our species very rational.

"Who killed Cock Robin?" Is quite an important question when posed scientifically. Only by answering such questions can we determine whether natural selection is really the driving force behind evolution, as Darwin thought. A robin can live for as long as eleven years. A pair can also hatch out two broods of five or more eggs a year. Now the population of robins is fairly steady. If it increased by only one tenth per year, it would grow to 13,781 times its original number in a century. An average pair of robins which live to be adult probably produce at least twenty eggs. And if they lived under very sheltered conditions they could probably produce 100. Actually only two eggs would be needed if there were no untimely deaths. So we may say that the struggle for life accounts for nine out of ten robins actually begotten, and forty-nine out of fifty which could be begotten.

Lack concludes that where cats and boys are common, about half the nests are destroyed, though most of the nests at Dartington were successful. A few young die in the egg or in the nest, but about three quarters of those which leave the nest are dead within a year. Even of those which survive the perils of youth, more than half die within the next year. The average life of a robin seems to be about one year or less. So far as the causes of death are known, cats, mousetraps, and motor vehicles head the list, but probably cold and starvation are equally important. A robin redbreast in a cage may, as Blake said, put all heaven in a rage; but, if like Mr. Lack's cage, it is thirty feet long, twelve wide, and six high, the robin is quite willing to breed in it, and is much safer than outside.

Lack is, I believe, a schoolmaster,* and has done all this work in his spare time. I want to see a social organization in which everyone will have the leisure for scientific work. There is any amount to be done, even in towns. No one knows half as much about the sparrow as Lack has discovered about the robin. There are huge

* I am glad to say that he is now head of an ornithological institute.

gaps in our knowledge even about cats. We know still less about the habits of less conspicuous animals. As the pressure of war work falls off, I hope that many people who have been much too busy since 1939 will realise that in work of this character they cannot only find intense enjoyment, but make real contributions to science.

THE STARLING

Our migrant birds from the south are just (March, 1948) arriving or have recently arrived to spend the summer in Britain. Some have not come very far, but a good many of the swallows have flown all the way from South Africa. And the birds which have wintered in Britain are going northwards and eastwards. It is of one of these species that I am going to write, namely the starling. It is particularly interesting because it may give an answer to the question of how a species originates. For the starling seems to be splitting up into two species, as Darwin believed that species sometimes do. The starling is a remarkable bird in a number of ways. It is much more social than most British birds. During most of the year many starlings roost in huge communal roosts with up to a hundred thousands members, from which they may fly for twenty miles each day to feed. Whereas the robin, to take a familiar example, spends most of its time in quite a small area, and quarrels violently with other robins except its mate. Again there are about twice as many males as females, so it is not uncommon for a female starling to have two husbands. This again suggests that they are not so quarrelsome as most of our small birds.

But the most remarkable fact, first clearly proved by Dr. Bullough, of Leeds University, is that while the starlings which spend the summer, and breed, in England, spend their lives here; those which come here about October and leave in March, breed in Europe. The Scottish winter visitors go to Norway. The English winter visitors go as far east as Sweden and Latvia, and probably into Russia. This migration had been known for some time, but Dr. Bullough was the first to distinguish the two types by the fact that the British, or sedentary race, has much lighter coloured beaks, especially in December and January. This was confirmed by putting coloured rings on the legs of a number of starlings, and observing

that the dark beaked ones went away in March.

The reason for the different behaviour of the two types is this. During the winter the continental birds have very small ovaries and testicles, and show no sexual behaviour. But although these organs get smaller in the British race after the breeding season in April, they increase in size in autumn, and there is a good deal of love-making, and sometimes even mating.

Now it seems to be a fairly general rule that the presence of sex hormones not merely makes a bird amorous of the other sex, but makes it attached to its place of breeding. The continental starlings fly back to their breeding places where their sexual organs mature in spring. The British birds not only never leave Britain, but they never move permanently away from their homes except in their first year of life, before they are sexually mature.

It is not safe to guess too much about the emotions of animals. But it certainly looks as if the emotions of birds towards their homes and their mates were similar. This is true of some human beings too. I have known at least one man who complained that his wife seemed to think she was married to her house, not her husband.

There seems to be little doubt that membership of the two "races" of starling is hereditary, and fixed for life. This means that they do not breed together, any more than the sewer rat and the ship rat. Very possibly an occasional abnormal continental starling remains in Britain, or a British one goes east. It is probable that if they got the chance, they could and would breed together, but this is not known.

The two races differ in a great many habits as well as their migration. For example, the continental starlings never seem to roost in towns, whereas many of the British ones do so. Among the well-known London roosts are the Marble Arch, and St. Martin's, Trafalgar Square. Again the British birds are rather less social than the continental ones. Some never seem to join communal

roosts. Other only do so in July and August after the breeding season. But there is no hostility between the two races. On the contrary, the British starlings are more tolerant of foreign birds than of their compatriots, probably because the latter are more apt to be sexually active, and thus arouse their jealousy. There are slight differences in the feathers of the two races, and in their eye colours, but not enough to enable one to distinguish between them with certainty.

It is very unlikely that the separation goes back even as far as ten thousand years. For ten thousand years ago, as we know from plant remains, England was a good deal colder than it is now, and would not have been a suitable winter refuge for birds. From what we know of the rate at which species originate, it is likely to be another twenty thousand years or more before the two races of starling evolve into a pair of species. One can guess at some of the possible lines of divergence. The continental starlings have farther to fly, and may be expected to develop rather more powerful wings. The English ones spend more of their times in holes and therefore rub their feathers more. They are likely to develop stouter breast feathers.

Other species of birds are probably splitting in a similar way. Thus Promptov finds that the chaffinches of Ukraine are divided into 'two' groups which do not inter-breed, on the basis of their song. Naturally we cannot expect to see species formed under our eyes in nature, though something very like it can be achieved in the laboratory. Thus Kozhevnikov produced a race of the fly *Drosophila melanogaster* which breeds true but gives sterile eggs when mated with the parent race. Nevertheless our starlings give us a fairly good idea of one of the many ways in which a species can split in two. I wish we could resurrect Darwin, if only for five minutes, to tell him about it.

CLEVER BIRDS

When biologists accepted Darwin's theory that men were descended from animals, they naturally tried to find some way of estimating intelligence in animals.

The chimpanzee and orang-outan came out very high. In particular Köhler found that some chimpanzees showed a good deal of intelligence in the use of solid objects as tools. They would pile boxes on one another to reach a suspended fruit. If given two canes, neither long enough to reach a fruit outside their cage, they would fit the narrower one into the broader in order to make a rod which was long enough. Clearly chimpanzees have at least a rudiment of the sort of intelligence which is developed in a skilled craftsman.

On the other hand Yerkes tried in vain to find in them the germs of mathematical intelligence such as we display when we take the second turn on the right, or bring home three loaves, not two or four. One of his methods was to give the animals a choice of a number of boxes, say nine in a row, of which some were open and some shut. If food were put in the left-hand box of those which were open, the apes sometimes got the idea. But they never managed to grasp the idea that food would be found in the leftmost open box but one. It was of course necessary not always to put the food in the same box. Animals easily pick up clues from small marks on wood, smells, and so on.

Other mammals were not much better, though two pigs did surprisingly well. Coburn and Yerkes managed to teach to crows to choose the farthest open door on the right, but it was a slow business, and they never mastered the choice of the first from the left completely. On the other hand Sadovinkova reported much greater success with two canaries, a goldfinch and a bullfinch. One of the

canaries was a dunce, but the others all beat Yerkes' apes. The goldfinch, after two lessons, always chose the second, starting from the left, of four open doors. When anything from three to nine doors were left open, he made one mistake. Later on he learned to pick the middle door out of three, five, seven or nine open ones.

Sadovinkova's work was not followed up till 1943, when a Finnish biologist, von Haartman, repeated it using fly-catchers, a lark and two bullfinches. He reports his results in the first number of *Behaviour*, a journal published in Holland, and devoted to animal psychology. Other authors describe the behaviour of wasps, mice and sticklebacks in the same journal. The young of a pair of flycatchers were put in a box near the old nest, and the parents had to learn to visit the first open door below the top one of a series. The mother finally managed to solve the problem correctly ten times running. The father generally made three or four mistakes out of ten.

The larks and bullfinches were kept in cages with a range of boxes from which to choose food. The bullfinch were "punished" for a wrong choice by letting down a screen in front of all the openings. The lark was too easily frightened for this to be done. The hen bullfinch was the best learner. She could choose the second opening from the right out of a variable number, and when the distance between holes varied from two to six inches.

It is easy to see why small birds should have this very specialised kind of intelligence. They have little or no sense of smell, and owing to the hardness of their beaks they can have little detailed sense of touch. They rely mainly on sight and hearing, though of course they may have a sense unknown to us which helps them in migration. They find their way through woods and thickets, or return to a nest in the middle of a meadow, by sight. So not only is their sight keen, but they can recognise objects and patterns to a surprising extent. The fact that they can learn tunes proves that they have an equally good memory for sound patterns.

They are remarkably good at building nests with such a clumsy organ as the beak, but we could not expect them to develop the manual skill and insight of an animal like the chimpanzee with a pair of hands. Only one bird is known to use a tool. This is a finch in the Galapagos Islands which uses a cactus thorn for picking out insects from under bark, as other birds use their sharp beaks. It would be interesting to test its intelligence in other respects. Our own thrush, of course, uses hard stones against which to crack snail shells, so it is near to the tool-using stage, but I hardly think it can be regarded as a tool-user.

These experiments are interesting in two ways. They show that small birds have a good deal of intelligence, as many people who have kept canaries and budgerigars have said for a long time. And they suggest that the kind of intelligence on which psychologists tried to concentrate is not the most important kind. It is a capacity for picking out resemblances and differences rather than one for solving the problems which arise in real life.

It is of course much easier to devise tests of this abstract kind, either for birds or men, than tests which will measure one's capacity for getting a machine or a committee to work properly, still more for inventing new kinds of machine or of social organisation. But I suspect that the mental qualities which psychologists can so far measure, or at least grade, are not the most important ones for human society. There is nothing surprising in this. They have only been at work on these problems for a generation or two.

It was a long time before physicists could measure the qualities of a metal or a textile material as well as experienced craftsmen could do. Psychologists have already made great steps in the right direction, but they still have a long way to go. And they do not always take account of the fact that the qualities which make for success in different kinds of society are very different. Men who achieve peerages in England would often be jailed in the Soviet Union, and men who would have been in high positions there have

been jailed here. Probably both these types of successful men would have been failures in the Middle Ages or in many primitive human societies. In fact human abilities can only be judged against a social background.

So perhaps it is a good thing that some psychologists should work on animals, where this kind of bias does not operate. It may help them to think more clearly about men and women.

HOW BEES COMMUNICATE

Eight years ago I gave an account in the *Daily Worker* of the early work of von Frisch and others on the language of bees. In July 1947 I was at the London Zoo with Professor Hadorn of Zurich. We watched bees coming in to the glass-fronted hive laden with pollen of different colours in the bags on their legs. He was able, by watching them, to tell me from what direction they had come, and roughly from what distance. So will you be, after reading this article. The facts previously known were these. When a bee has found a rich source of pollen or honey she comes back to the hive, and before handing it over to the other workers whose job it is to store it in the comb, she does a peculiar "dance". During the dance other bees touch her with their antennae, so that they know what smell is associated with the kind of food in question. They then fly off to visit flowers of the same kind, or dishes of sugar water impregnated with the same smell, for example of peppermint.

When the flower or the sugar-water is placed within fifty yards of the hive, bees fly out in all directions to visit flowers or dishes with the same smell. But when they are placed at distances over about a hundred yards, they not merely fly out in the right direction, but for the right distance. As some of them arrive before the original finder has unloaded her honey or pollen it is clear that she must have told them in which direction to go, and how far.

Von Frisch has discovered how the information is conveyed. If the food is within fifty yards the finder always dances round and round. If it is more than a hundred the dance is quite different. She goes forward in a certain direction for an inch or two, waggling her abdomen, then runs back without any "dancing" and repeats the dance again and again. The more she has found, and the

sweeter the sugar-water, the longer the dance lasts and therefore the more other bees are able to learn what smell is associated with food, and the more go to look for it.

If the finder dances the round dance they go out in all directions, but not for further than a hundred yards. The other kind of dance gives them the direction. The dances are generally carried out on the comb, but sometimes on the landing stage in front of a hive. If it is horizontal, the dancer moves in the direction of the food, and the other bees fly out in the direction of her dance.

If however the surface of the comb is vertical, something much odder happens. As the day goes on, the dancer moves in different directions after coming from the same place. Supposing the food is south-west from the hive, then at 9 a.m. the dancer moves horizontally to the left, at noon she moves at forty-five degrees upwards, at 3 p.m. vertically upwards, and so on. In fact a dance upwards means that the food is in the same direction as the sun, a dance to the right that it is to the right of the sun, and so on. It is most remarkable that bees know the direction of the sun, even in cloudy weather. The distance is given by the rhythm of the dance. Food only 150 yards away elicits a dance with 40 tailwags a minute. This number sinks to 20 when the food is half a mile away, and to only 8 at a distance of two miles.

Von Frisch believes that the same language is used by scouts which go out from a swarm of bees and come back to tell it where they have found a place suitable for a new hive. But this is uncertain, for swarming is rare, whereas hundreds of observations can be made every summer day in an ordinary hive.

Besides the dances the bees have at lease one other "word", namely a sweet smell which they make when they have found rich food, and which attracts other bees to the place.

These observations seem to have a great philosophical importance. It is often said that animal "language" is a mere

expression of the emotions, and cannot convey statements of fact. But it is clear that the bees can tell each other not merely that they have found food, but where they have found it. It is true that the bees' language seems to be inborn, and not learned like ours. It is like that of the young lady in Shaw's *Back to Methusaleh* who emerges from an egg talking perfect Shavian English. However some birds have to learn a good deal of their language. It is also clear that bees have an amazing sense of direction. If a hive is turned round the dancer moves over the comb in a carved path as if she had a compass needle in her head. Perhaps she has some kind of magnetic sense which we lack. Her perception of rhythm must also be superior to our own.

A reader may well ask whether it is not possible that Von Frisch is pulling our legs, or at least letting his imagination run away with him, and has invented the amazing story. The answer is that although he made some mistakes in his interpretations of dancing, most of his earlier work has not only been confirmed but applied in practice by Gubin, Komarov and others in the Soviet Union, as well as by von Frisch himself in Germany and Austria.

Red clover is normally fertilized by bumble bees, and does not set seed without fertilization. Bumble bees are not common enough to fertilize an area of an acre or more of red clover. And ordinary bees prefer other flowers as their probosces are not long enough to get all the nectar of a red clover flower. The following method is therefore used. Beehives are brought near to the clover fields. Glasses containing sugar water and red clover blossoms are placed among the clover. Bees soon find them and come back to dance. Their comrades fall for the propaganda and search for flowers with the correct smell. A few of them find the sugar-water. The majority search the clover flowers. They do not find much nectar there, but in their searches they carry pollen from one flower to another. Enough of them find sugar-water to keep up the stream of propaganda in the hive.

The system rather reminds me of the football pools where a few people win large prizes, but the vast majority merely enrich the organisers of the pools and keep the postal workers busy. Economically it pays the seedsmen. For an expenditure of about twelve pounds of sugar per acre over five weeks von Frisch got an increased yield of 36 pounds of clover seed per acre. As a pound of clover seed cost as much as 16 pounds of sugar this was a good bargain, except perhaps for the bees.

Possibly an even bigger return could be got by inducing bees to visit orchards. It is important that the bees visiting prepared sugar-water should if possible perch on fruit blossom and also suck up juice into which blossom has been crushed to give it the right scent. I do not know whether we shall be able to learn the language of ants, and get them to clean our kitchen floors instead of raiding our sugar. But I am quite sure that research on these subjects will tell us things which we need to know, not only about animals, but about human societies.

HOW BEES FIND THEIR WAY

I have written several articles on the work of von Frisch on the senses of bees, and their methods of communication. Quite recently he has made a discovery which may clear up a lot of the so-called mysteries of animal behaviour.

The bees certainly perceive forms and colours. More accurately they can be trained to distinguish them. Their colour sense is excellent, but their form sense is nothing like as good as our own or a bird's. But they also perceive a quality in light which we do not, namely polarisation. When light passes through certain crystals it is of course bent out of its path. But instead of one ray coming out of the crystal two do so with rather different properties.

The electrical vibrations which constitute ordinary light are in all directions at right angles to its direction of travel. But in a beam of polarised light coming out of a crystal they are only in one direction. For example if the light is going northwards the vibrations could be up and down, or east and west, but always in the same plane. One can make a crystal prism which only lets through light polarised in a particular plane, and by turning it round see in which plane a particular beam is polarised. Sugars, and many other substances with asymmetrical molecules, rotate the plane of polarised light passed through water in which they are dissolved, and this property is used to measure sugar with great accuracy.

Von Frisch found that bees returning from a good source of honey or pollen indicate its direction to their comrades by a peculiar dance. If this dance is done on a flat surface it consists of a series of runs in the direction of the food, with more leisurely returns in a curved path. If it is done on a vertical surface, such as the honey comb, upwards indicates the direction of the sun. So if the sun is in the south and the food to the south-west, they

run upwards at an angle of forty-five degrees to the right of the vertical. Von Frisch found that if he gave them a flat surface to dance on, and put over this a double glass sheet with crystals between the glasses which only lets through light polarised in one direction, the direction of the dance was altered.

What does this mean? Direct sunlight is not polarised, but the light from the rest of the sky, particularly from clear blue sky, is so. So is light reflected from anything, though it is not so strongly polarised as light passed through some crystals. That is why motorists can cut out the glare of reflections from a wet road by using "polaroid" spectacles or windscreens. The bee is guided not so much by the sun, which may be hidden by clouds, as by the polarisation of the light from the sky. And it is fooled by substituting artificially polarised light for the naturally polarised daylight.

We distinguish the up and down direction without thinking. The bees, at any rate when there is even a small patch of blue sky, can distinguish the direction of the sun, even when the sun is behind a cloud. Of course we have no idea what polarised light looks like to them, but nor have we any idea whether their colour sense is at all like ours. It may be more like our sense of musical pitch or of smell. But the result is as if what to us is a uniformly coloured surface were ruled with fine lines in one direction, gradually changing in the course of a day.

A great many other insects are remarkably good at finding their way back to their nests, and zoologists will probably be occupied for some years to come in finding out whether they too perceive polarization. It is possible, but unlikely, that birds have similar powers. It is unlikely because migrating birds fly over the sea at night, and keep a pretty true course.

A number of suggestions have been made as to how birds find their way, and many have been disproved. They might, for example, be sensitive to the earth's magnetism, like a compass. But if so they would be upset by strong magnets, which they are

not. But the discovery concerning bees suggests that they may be aware of some directional quality in their surroundings to which men are insensitive. This may turn out to be something well known, like polarised light. It may also be that they rely on some happenings which physicists have not detected. If so the discovery of how birds are guided during migration will also be the discovery of a new physical phenomenon, perhaps of very great importance.

The interest of von Frisch's discovery is two-fold. It is the first time that a sense has been found in animals quite different from any of our own. No doubt a dog can smell much better than we, and his sense of the direction of a sound is also much better than our own. But we know what smell is, and can roughly locate a sound. If a dog were aware of magnetism or of radio waves, we should have something more like the bees' new sense.

Secondly, it warns us how careful we must be in interpreting the behaviour of animals as if the world appeared to them as it does to us. We are apt to credit them with wonderful instincts or intuition when they merely perceive things which we can only detect with complicated apparatus. There is only one world, but it must appear very different indeed to different kinds of animals, and we may yet learn a great deal about it by studying animal behaviour.

MOVIES FOR TOADS

Primitive men take it for granted that animals can think, and according to many religions they have souls which are judged after their deaths. Christian philosophers have usually denied that any other animals were capable of reasoning or had any rights. So, till the nineteenth century at any rate, animals were better treated in India than in Europe. Darwin took the view that the higher animals possessed most of the human faculties, though many of them poorly developed. On the other hand some of the more mechanistic biologists try to explain all animal behaviour on mechanical lines.

It is extraordinarily difficult to be sure that animals are thinking, and not picking up clues given by the experimenter. For example about 1910 a German at Elberfeld had some horses which could do fairly elaborate arithmetic, such as extracting cube roots. A French journalist, zealous for his country's honour, produced the story of a cat at Bordeaux which corrected the children's homework, mewing when there was a mistake in a sum and purring when it was right. However no one ever saw this cat, and plenty of people saw the horses. When a sum was put up on the blackboard, they tapped out the answer with their hooves. But they did not do it unless the teacher was there, and the psychologists who examined them finally concluded that they watched him carefully, and stopped tapping when he wished them to. Perhaps he made some signal deliberately; more probably they noticed slight changes in his expression or breathing.

A better idea of an animal's capacity for grasping numbers comes from the experiments of the late Dr. Honigmann on hens. He put hens in a cage with a narrow gap in the floor. Under this gap a board moved on rollers, carrying a row of wheat grains, of which the hen could pick one at a time. He glued down every second wheat

grain, so that the hen could not remove it. After a while some hens learned only to pick at alternate grains. But they failed completely to conform to the situation when only every third wheat grain was free. If we like to put it that way, we can say that a hen can count up to two, but not to three. Other birds seem to be able to count up to five or so, or at least to notice a difference between four and five eggs.

Another of Dr. Honigmann's experiments was probably still more interesting. It has often been stated that animals cannot appreciate pictures. Certainly they recognise gramophone records. And female crickets will come to a telephone if a male of their species in chirping at the other end. But a dog rarely, if ever, shows any interest in a picture or photograph of his master or another dog. Nor is he interested in cinema films.*

The first animals which undoubtedly reacted to a moving picture are the common toad and the natterjack toad. They have very simple minds, if mind is the right word. They will only eat moving objects. The response to food is very characteristic. Although it is slow in its ordinary movements, a toad can flick out its tongue with very great speed and accuracy, and bring back a small insect or other food into its open mouth. It then swallows it if the taste is suitable. They are not interested in dead mealworms if they stay still. But a toad will flick and snap at a dead mealworm if it is dragged past the toad, especially if there is a well-marked background behind it. The toad snaps in the same way if the mealworm stays still, and the toad and the background are dragged past it. Toads will also snap at a film of a moving mealworm or other small animal. It might be argued that they react mechanically to any small object which moves or seems to be moving. But this is not the whole story.

If two toads are competing for the same food, and one of

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* Several correspondents claim that their dogs enjoy film, particularly of the "Wild West" type

them gets it, the disappointed toad, especially if hungry, may flick its tongue at the eye of its successful rival. This is particularly common if the successful toad is the smaller of the two. Honigmann made films of toads eating, and showed them to other hungry toads. I have myself seen them flicking the film star in the eye with their tongues. But this is more constantly done if the film is shown a little less than life size and rarely happens if it is enlarged. The toad is not a noble animal. A toad will attack a picture of itself feeding as readily as that of another toad, but it is quite uninterested in films of other small animals, such as hamsters, feeding.

Encouraged by his success with toads, Honigman went on to show his films of moving worms to dragonfly larvae. These live under water, and shoot out their jaws at their prey. The film had to be shown projected onto a sheet of white paper pasted on the side of a glass tank, and the insects snapped at the pictures.

It is curious that so far moving pictures have only interested animals with very simple minds, such as toads and dragonfly larvae, and those with very complicated ones, namely ourselves. I think the reason is clear. A dog or a cat has mind enough to know that the moving picture is not a real happening, though a few dogs will watch films representing vigorous action. Men alone have negated this negation. We know that the hero is not really in danger of the electric chair, and that we shall not meet the heroine even if we stay at the stage door all night. But in spite of this, we manage to work up the appropriate emotions in a minor key, so to say.

I have described these particular experiments rather than hundreds of others which are constantly being made on animal behaviour, largely because I liked Dr. Honigmann, a refugee who worked at the London Zoo before the war, was interned, and carried out his work on toads in Glasgow until his death. I liked him partly because he so obviously liked toads. While one can go too far in treating animals like human beings, I believe that one achieves the best results, whether with animals, plants, or men, if one likes them as well as being interested in them.

THE STRUGGLE FOR LIFE

All the biologists known to me accept the theory of evolution in some form, though a few postulate supernatural intervention at certain stages. As to why it happened there is far less agreement, but I think a big majority believe that natural selection is one of its main agencies. It is extremely hard to watch natural selection at work. To do so we must first show that some character is inherited, and then prove that animals or plants possessing it are more likely to survive to maturity or more fertile when they become mature, than the rest of the species, and that in consequence the character is spreading.

Probably the best demonstration of natural selection at work is that of Dubinin and his colleagues. He showed that within a species of fly, a particular type increased during warm weather, and decreased in the winter. He also showed that the kind favoured by warmth was commoner in towns than in the country, but no commoner on the sites of towns which had been destroyed by the Germans. By laboratory experiments he showed that the type which increases during the warm weather is much more easily killed by cold than the other type.

However, a really thorough study will require counts of the numbers of an animal species over many years, including a study of the reasons why members of it die at different periods. A study of an animal population on these lines has just been published by G.C. Varley. It has not yet got to the stage where natural selection was observed, but it gives an idea of how such work will have to be carried out in future. Clearly it is easiest to work with an animal which spends most of its life in the same place. He chose a gall fly which lays its eggs in the flowers of the common knap-weed (something like a large daisy), and spends most of its life as a grub inside the gall which it forms there.

Even when adult it does not generally move far. He marked 108 flies with spots of paint, and even after a fortnight found none more than 22 yards away from the spot where they were let out. From counts of flies and grubs, he calculated that a female laid about 70 eggs in July 1935, 52 in 1936, and 200 in 1937. Since there are about equal numbers of males and females, and the species is not increasing or diminishing greatly in numbers, all but two of these must die before maturity in an average year.

A few eggs were addled. A fair number of grubs died before forming galls, but the biggest cause of mortality in summer and autumn was from other insects which lay their eggs in or near the grubs. When these eggs hatch, the gall-fly grubs are eaten alive. The large majority of the gall-fly grubs each year die in this slow and perhaps painful manner. Others were killed when caterpillars ate the flower heads in which they lived. About a quarter survived till winter, when most of the flower heads with galls fell off. A large number of these were eaten by mice, and others died when the ground was flooded. By spring 1938 only about one in forty of the generation survived. Parasites and birds further reduced this number, and by July an average of about two flies emerged from each batch of 200 eggs.

Varley went on to make similar calculations for the most important parasites. The fact that twenty-four insect species were found in the galls shows how immensely complicated even a very simple community proves to be. However, the most important parasite turned out to be dependent on the density of the hosts. Each female of the parasite species searches about 100 flowers for gall midge grubs. In a year where they were frequent she laid about 60 eggs, in a year when they were rare only about 9. In fact, when there are few gall midges, the number of parasites diminishes sharply. When there are many, it increases. So the parasites prevent the hosts from becoming very numerous, but cannot destroy them altogether.

What is much more surprising, if birds or mice eat some of the gall midge grubs, along with their parasites, this is a definite

advantage to the gall midge. It gains more from the destruction of parasites than from the destruction of its own species, and its numbers increase. This had been demonstrated on theoretical grounds by Volterra in Italy, and by Nicholson and Bailey in Australia, but Varley was the first to prove it by actual figures.

There is very little direct competition between the gall midges. When they are numerous there is a little competition for food, but when they are rare some females do not find mates, and lay sterile eggs, and these two effects roughly balance one another. The danger from overcrowding comes not from direct competition, but from increase in the number of parasites. Man was in the same condition till very recently. The death rate from disease in towns was so great that human populations could not increase beyond a moderate density.

By giving towns a water supply uncontaminated with sewage, and by other hygienic measures, we have put an end to this state of affairs. But unfortunately in other respects we are still in a state rather like that of gall-fly grubs. It is only public misfortunes which enable us to cope with human parasitism. As a result of the war we had to adopt rationing, and in consequence about a third of our people have better food and clothing than they had in 1919. Whether they will continue to get them much longer in another question. The peoples of Eastern Europe have only been able to shake off the worst of their human parasites after a ghastly period of oppression and war. The Communists of Western Europe, who would like to do the same thing without massacres and foreign invasions, are accused of trying to produce the chaos which they want to prevent.

The gall midges cannot think. They have to rely on birds to eat their parasites, even if a great many of themselves are eaten along with them. Men can think, but most of them find the process pretty unpleasant. It is time we did a little serious thinking along the lines of Britain's Plan for Prosperity. If we do not do so, we may find ourselves in a position rather too like that of the gall midges.

MAN'S ANCESTRY

When Thomas Huxley first produced serious evidence that man was descended from an ape-like ancestor, his critics quite rightly pointed out that there was large gap between men and apes, and that no fossils were known which bridged this gap.

For such hypothetical fossils they coined the phrase "missing links". Since that day two essential links have been added. Dubois found skulls and other bones in Java which he assigned to the genus *Pithecanthropus.* There was doubt as to whether they were apes or men. There is not much doubt now, because very similar skulls from the neighbourhood of Pekin were associated with stone tools, and palaeontologists are agreed that an ape-like creature which used tools deserves the right to be called man. So far as I know the first person to make this point was Marx's colleague Engels in an essay reprinted in *Dialectics of Nature.* Very likely the idea came from Marx. At any rate it is generally accepted now by people who would be horrified to be called Marxists.

These very primitive men had brains a good deal smaller than ours, prominent ridges above the eye sockets, no chins, and various other rather ape-like features. But they obviously used their hands as we do, though probably not so skilfully. Gigantic forms closely related to the Java and Pekin men have also been found in Java and China. We do not yet know enough about them to say whether they are likely ancestors of humanity.

In the last twenty years a new, and perhaps more important, links has been found in South Africa. Dart found the skull of a baby and since then Broom has found skulls and various other bones of a number of adults, in hard stalagmitic deposits in caves. These skulls are far more ape-like than those of the Java or Pekin men. There was

no trace of a forehead, and the mouth came out in a regular snout. At first sight they might only be skulls of apes a little more man-like than the chimpanzee. At least one distinguished anatomist takes this view.

But Broom, and Legros Clark, who has examined them on the spot, say that they are much more human than those of any ape, for the following reasons among others. There is no doubt that the tailless apes, the gorillas, chimpanzees, orangs and gibbons, are much nearer to us than any of the tailed monkeys, both in structure and in mental capacity. But they all differ from us in several ways. They have prominent canine teeth, which the males especially use in fighting. The hole through which the spinal cord enters the brain is set further back in the skull than in men, so that the head must be bent down to look forwards if they stand on their hind legs. And their legs are far less specialised than our own for standing. The heel is one of the human organs which differ most from that of the apes; and the pelvis, the bony basin which supports our abdominal organs, is also very different in men and apes. Finally the apes have arms which may be even longer than their legs, and are used in swinging below branches instead of walking above them on all fours as the tailed monkeys do.

In all these respects the South African fossils seem to be human rather than ape-like. Their dog teeth project little more than ours. This means that they probably fought with their arms, perhaps holding stones or sticks. The foramen magnum, the large hole in the base of the skull, is well forward as in man, not backward as in the apes. No complete arm bones have been found yet, but the fragments found suggest that the arms were short. Further the other animals whose bones are found with them in the caves were typical dwellers on the veldt, quite different from forest animals. This means that they lived in an environment where even though they climbed trees, they would not have been able to go for miles at a time by swinging from one branch to another. So very long arms would have been of no use to them.

Finally Broom has found not only a pelvis, but an astragalus, the bone which forms an arch at the instep between the heel and the rest of the foot, and supports the weight of the body. In each case the form was human, and it is reasonably sure that these animals walked on their hind legs. But yet their skulls were decidedly ape-like, apart from the modification at the back due to their owners standing up. And they left no tools or anything else suggesting that they could be called men. Their stature was probably rather less than that of any living human race.

It is possible that we are descended from these animals, but rather unlikely. But they show two things. In the first place there were animals with many human characters, but not human brains. If in another hundred years no such skeletons have been found anywhere but in South Africa, we may have to admit them as probable ancestors. However, it is quite possible that similar fossils will be found in other fairly dry areas, for example in Central Asia, when people start looking for them seriously.

Secondly, they show that it was possible for such animals to live, walking or running as men do, without human brains. But they were in a position to use their hands for something more skilled than holding on to branches, and if they did so, there was a selective advantage in developing their brains to control their hands. It is not at all sure that further brain development would be any advantage to an animal like a chimpanzee which already uses its hands very efficiently for grasping branches. It is certainly advantageous for an animal which is beginning to use tools, even of the crudest kind.

Moreover such an animal would gain much more from social behaviour than a chimpanzee. A chimpanzee can get away from a lion by climbing, and can move through the trees far faster than a leopard. A band of twenty chimpanzees would be no safer than a band of four. But on the ground a band of twenty, with sticks and stones, might put a lion to flight, while four could not. Combination

for hunting is also much more effective on the ground than in the trees. Whether or not the species discovered by Broom are actually ancestral to man, they give us a good working idea of what the animal species, which took to using tools and became men, was like.

Broom, by the way, is almost as worthy of study as the fossils which he has collected. He is now over eighty years old, but more vigorous than many men of forty. He is a qualified doctor, and has earned his living as a doctor first in Australia and then in South Africa working in country districts where he could spend most of his time studying first living animals and later fossils. In South Africa he collected a series of fossil forms which show how reptiles very gradually evolved into mammals. At the age of seventy or so he took up his present line of research with complete success.

Although it was not until the age when most scientists retire from work, that he was given a university appointment, he did the work of a dozen ordinary lifetimes in his spare time. It is good to think that such a man has made the most important discoveries of our generation concerning human evolution.

DARWINISM AND ITS PERVERSIONS

Most Marxists are Darwinists. Stalin was turned out of a theological seminary for reading a translation of one of Darwin's books. Nevertheless Darwinism has been used to defend highly anti-democratic ideas. The facts is, I think, that Darwin went badly wrong, not in his account of how evolution happened, but in his comments on the process.

We can state the theory of natural selection something like this, in modern terminology. If a number of animals or plants in a population carry a gene which makes them fitter than the rest of it, in the sense that on the average they leave more descendants behind them, that gene will tend to spread through the population. A gene is a structure in the cell nucleus usually, but not always, too small to see with a microscope, and handed on to the next generation by a process of copying. And of course fitness is not a mere matter of survival or fertility. An animal which looks after its young is fitter, in the Darwinian sense, than one which does not, because more of them survive to maturity. Natural selection does appear, as Darwin thought, to be the main driving force of evolution. In fact modern work has decisively confirmed its importance.

Unfortunately Darwin did not stop here. He wrote of natural selection "favouring the good and rejecting the bad", and even ventured to predict "And as natural selection acts solely by and for the good of each being, all corporeal and mental endowments will tend to progress towards perfection." Of course he realised that most lines of descent in the past had ended in extinction, but he apparently thought that this was always due to competition by "better" or more perfect species.

Marx and Engels pointed out that Darwin was severely biased

by his views as a well-to-do member of the English bourgeoisie. The passages quoted show that he did not draw a clear distinction between goodness and success, or might and right. The capitalist class begins to notice the distinction when things are going against it, as at present, though curiously enough it is still as convinced of its own righteousness as it was a hundred years ago, when only a few men like Marx saw that it was already preparing its own doom.

The fact however is that the survival of the fittest does not necessarily make a species of animals or plants fitter in any intelligible sense of the world. It usually does so, but it may equally make it less fit. In a great many species of mammals and birds polygamy prevails. The strongest males have a large number of mates, the weaker have none. In such species one usually finds that the males are considerably larger than the females. Thus male poultry and pheasants are larger than their hens. In the monogamous song birds the sexes are generally of the same size. In some highly polygamous animals such as the fur seal the disproportion is very great. Clearly where the males fight for the females, mere size is an advantage. It is not necessarily an advantage in the struggle with other species. A large seal is compelled to feed on large fish, and they may not be so numerous as small ones.

The record of fossils shows that very many species have progressively increased in size, very often with a development of horns or other such weapons in the male sex. This increase in size was often the prelude to extinction. The large species died out, while smaller ones lived on.

Specializations of all kinds may give an advantage to their possessors. Many of our common insects can only live on one kind of plant. So long as the plant is common, natural selection will tend to favour those which are particularly well adapted to it. But once a rigid specialization is established, if the plant dies out, so does the insect.

Of course, very occasionally an extreme specialization opens up a new field to an animal. For example the transformation of the front legs into wings allowed the birds and bats to conquer the air. But usually such specialization only enables animals or plants to use a limited habitat, for example caves or cliff-faces. Sometimes these specialists have a stroke of luck. For example, the pigeon, which is a cliff-dweller when wild, has found artificial cliffs in the buildings of London.

Even an apparently advantageous adaptation may reduce the numbers of a species. If a new gene appears in a species of insect which makes it less conspicuous to birds, natural selection is likely to make it spread throughout the species. But if the same insect is attacked by an internal parasite, so many parasites may survive that the numbers are actually reduced.

Natural selection is, I believe, the main agent of evolution. And it certainly prevents animals from losing useful organs and instincts, as they may do when domesticated. But it is a blind force, not necessarily beneficial, in the long run. I think it probable that many species have become extinct as the result of natural selection, which forced them into evolutionary paths which were blind alleys.

In the same way economic forces determine the development of human societies, as Marx first clearly saw. But whereas the earlier economists, such as Adam Smith, thought that economic competition would necessarily make all nations richer, we now see that this is not true. On the contrary, competitive capitalism, by the survival of the few "fittest" businesses, inevitably develops into monopolism. Fortunately Marxists see that there is a way out. But they have a big task to convince their neighbours, and a terribly short time for their task.

I think that future students of evolution will build on Darwin's work as Marx build on that of Smith, Ricardo and others. But this will only be done by a study of natural selection at work. Its time scale is so much slower than that of economics that we cannot hope

for the necessary knowledge in one human generation. For this reason it is necessary to apply dialectical thinking to Darwinism. Until we get it, it is futile and dangerous to talk about controlling human evolution. Hitler tried to do it. Hitler is dead, but his ideas are alive, and we must be very careful to see that Darwinism is not made the basis of new Hitlerism.

THE MATHEMATICS OF EVOLUTION

The greatest difficulty in explaining science to ordinary people is that almost every part of it is becoming mathematical. The mathematics are not always very difficult. For example you do not need much more mathematics to study heredity than to study contract bridge. But you do need some.

One of the studies which is rapidly becoming mathematical is that of evolution. Darwin thought in words. His successors to-day have to think in numbers. Everyone who has gone into the evidence, which takes some years to do, believes in evolution. That is to say he believes that the animals and plants living to-day are descended from very different ones in the past, some of which have left fossils. But there is a good deal of doubt as to some of the lines of descent and an immense amount about how evolution happened.

Most biologists think an explanation based on natural selection will account for it. But some believe, with Lamarck, that acquired characters are inherited, for example that if you feed a hen well, not only will it lay more eggs, but so will its daughters. Others believe evolution is divinely guided, in spite of the fact that this puts the responsibility for the tapeworm and the tubercle bacillus on God (for there were certainly parasites long before there were any men to sin). Still others say they don't know.

The first place where mathematics come in is in fixing the time scale. This can be done by analysing radioactive minerals. For uranium and thorium gradually transform themselves into lead, which has a different atomic weight from ordinary lead. And the older a radioactive mineral the more of this special type of lead it will contain.

The next step is to measure a number of fossils carefully in

order to see just how much change has occurred in, say, two million years of evolution. The results are astonishing. The teeth of horses have been getting longer for some fifty million years. Their ancestors were browsers, that is to say they ate the leaves of trees, for which they only needed short teeth. But grass is a good deal grittier than tree leaves, besides containing grit from the soil, and wears the teeth down. So a short-toothed animal could only live for a year or so on grass. It would die when its teeth were worn away. But teeth have changed so slowly that if you measure corresponding teeth from a population of fossil horses and from their descendants two million years later, although the average values have changed, there is often still some overlap. That is to say the shortest teeth two million years later are no longer than the longest two million years past.

The next step is to see if you can change the characters of a population by exposing it to natural selection under controlled conditions. This has been done with populations of flies by Dubinin in the Soviet Union, by Dobzhansky in the United States, by Kalmus in England and above all by Teissier in France. The mathematical theory of these changes is fairly complicated, and a part of it was worked out by myself before any of these experiments had been done, while Wright and Fisher have tackled some of the still more complicated problems which arise in natural evolution.

Curiously enough we know more about natural selection in man than in any other animal or plant. The reason is a simple one. One can study human beings with various inherited abnormalities and see how long on an average they live and how many children they have. One cannot do this with wild animals. White mice in captivity are just as fit as coloured ones. They live about as long and have as many children. And whites do not disappear from a mixed population. But they are less fit in the wild state, probably because they do not see as well as normal mice, and are more conspicuous to their enemies. However, one cannot study a thousand wild white mice and a thousand coloured ones, and see just how the white ones are less fit. One can make such studies on hundreds of human

dwarfs or haemophilics, that is to say boys whose blood clots very slowly.

So the most immediate application of the mathematical theory of natural selection has been to human society. Unfortunately most of the ladies and gentlemen who wish to improve the human race seem to find the theory a bit too stiff. I do not blame them for finding it stiff. I do blame them for putting forward eugenical schemes without the necessary mathematics. This is as futile as trying to design a high-speed aeroplane without mathematics, and a lot more dangerous. For a badly designed aeroplane will probably only kill a few pilots and passengers. But false ideas about racial biology may lead to the death of millions, as Hitler demonstrated.

In fact the theory shows that some "racial hygiene" is possible, but that it is far less efficient than has been thought. We could prevent about half the haemophilics from being born, and about a quarter of the dwarfs. In either case we should have to interfere with human liberty to some extent. I doubt if it would be worth while. It would be still harder to stop mental defectives from being born, for the good reason that most of their parents are normal. This does not mean that it will always be impossible either to prevent the birth of such children, or to treat them so that they grown up into rational people.

To come back to evolution, I think it has been proved that natural selection is an effective agent, and will explain a very great deal of what has happened. But some changes are certainly harder to explain than others; and I think it is still an open question whether all evolutionary change can be explained in this way. What I am sure of is that it is as useless to argue about some of these doubtful cases in words as to argue in words about whether or not an aeroplane will ever fly faster than sound.

The fact that science is getting more mathematical is one of my main difficulties in explaining it. The remedy is for children to learn more mathematics, which they could do if mathematics

were brought into relation with real life, instead of with ridiculous problems about the price of eggs, which is controlled anyway. But till my readers know more mathematics, I have to write more dogmatically than I like.

LANGEVIN

When Paul Langevin died in 1946, I was asked to write an obituary. I had to refuse, for the good reason that I did not know enough about his scientific work. I knew that he had advanced many branches of physics and that he was one of the two foreigners to whom the Royal Society had awarded two of its medals. I was far from clear as to exactly what he had done. Only by reading the last number of *la Pensee*, the great French review which he founded, have I been able to find out the measure of his achievements.

In 1897, he came over to Cambridge with a scholarship from the City of Paris to work under J.J. Thomson, who was carrying out the research on electric conduction through gases which led to the discovery of electrons, and his first ten papers were records and interpretations of experimental work on this subject.

In 1905, he published three theoretical papers on magnetism, on relativity, and on the movements of molecules in gases. I think other physicists admired Langevin's work on magnetism above anything else which he had done. Magnetism is an example of what is called a co-operative phenomenon. The individual atoms in a magnetized iron bar are no different from those in an unmagnetized one. Nor is their arrangement different. But they have a tendency to face in the same direction, and as each one is a little magnet, the bar becomes a magnet too.

So much had been guessed for a long time. Langevin was the first to approach the problem dialectically, through as far as I know he was not then a Marxist. He looked for a conflict between the influences making for a regular arrangement of atomic directions and something else. He found the antagonist in heat. The hotter the iron bar the more the atoms will be jostled out of their agreement in

direction, and the less will be the amount of magnetism produced by a given current. This and a number of other similar facts, were known before Langevin was able to calculate what happened in a number of special cases, and a large amount of experimental work by others verified his calculations.

He also predicted a quite new phenomenon, namely that when a body is magnetized, its temperature rises, though often only be a few hundredths of a degree. This was found to be the case, and is now the basis of the method used for producing the greatest extreme of cold so far reached. Gases are liquefied by making them do work in expanding rapidly. The liquefied gases are cooled still further and even frozen by letting them evaporate. A temperature is reached when they can evaporate no more. Certain crystals are then put in a magnetic field and cooled down as far as possible. The magnetic field is then taken away, and they cool down still further. A large fraction of the small amount of heat left in them is used up in destroying the regularity produced by the magnetic field. Thus the study of the conflict between temperature and magnetism gave not only a more exact theory of magnetism, applicable in principle to other properties of matter, but a new technical method which may be the basis of industries a generation hence.

The theoretical work on relativity was the first of a series which not merely confirmed Einstein's work but extended it considerably. Einstein, in his obituary, wrote of Langevin : "It seems certain to me that he would have developed the special theory of relativity had this not been done elsewhere; for he had clearly recognised its essential points".

What he did was to apply it to chemistry. It had long been known that the atomic weights of the elements were not exactly whole numbers when that of hydrogen is taken as a unit. In 1913, Langevin suggested that this was due to the fact that energy has weight and mass. This principle could not be applied correctly till Aston had weighed atoms correctly to one part in a thousand, ten

years later. It is now accepted by all physicists. If we take the atomic weight of hydrogen as one, those of the two different kinds of iron atom are not exactly 54 and 56, but nearly one per cent, below these values. This is because if we could build up iron atoms from hydrogen a lot of energy would be lost, and this energy has weight. A similar calculation from atomic weights gives the energy liberated by an atomic bomb.

Now comes a rather amazing coincidence. Every communist ought to read Jack London's novel *The Iron Heel* in which he predicted the coming of fascism. He was quite right regarding its successful splitting of the workers' movement, and its extreme cruelty. Not being a Marxist, he did not see that it would be unstable, and could not last even for a generation, instead of the centuries which he predicted. The book is supposed to be written by the widow of a socialist leader, Everhard, who had been executed by the fascists. Her father, a Californian professor, and himself a convert to socialism, had discovered the identity of matter and energy.

Langevin cannot be said to have done this. He only showed that some of the weight and mass of atoms was that of the energy in them. It is not yet sure that all the weight and mass can be converted into any form of energy. However, his daughter Helene married Jacques Solomon, a physicist, and one of the many communists who were shot by the Gestapo during the German occupation. Langevin was imprisoned in 1940, but later released, after which he escaped to Switzerland when again threatened with arrest.

From 1905 onwards his publications become more and more mathematical, and it looked as if he had abandoned experimental work. However, during the First World War he started research on the production of beams of supersonic vibrations in water. Ordinary sound waves spread rapidly, and turn corners easily. But trains of waves too shrill to hear behave much more like light, and can be used

like a searchlight beam or a headlamp to detect obstacles under water, or even submarines. Both as a source of such waves and for detecting them he used the phenomenon of piezo-electricity discovered by the Curie brothers. A quartz disc in an alternating electric field contracts and expands as the field changes, and will similarly translate changes of pressure into electric surges. His work in this field has not only been used under water, but in radio engineering, in the design of very accurate clocks, and in many other fields of practical work. I have no space to mention his work on chemistry, on radioactivity, on units of measurement, and even on why the sky is blue.

He took teaching very seriously. Although he wrote a number of books, he never published his courses of lectures on physics; however there can be no doubt that they had a very great influence in bringing the teaching of this subject up to date, and above all in welding it into a unity rather than a series of branches such as light, heat, sound, electricity and magnetism.

As early as 1925, he was one of the founders of a movement which led to the foundation in 1932 of the *Universite ouvrierie*, that is to say the Workers' University, of Paris. Daladier suppressed it in 1939, but it was born again in 1945 as the *Universite nouvelle.*

He was also an ardent supporter of the *Ligue des Droits del' Homme*, an organisation which did similar work in France to Civil Liberties in Britain. Up to 1936, he showed some learnings towards an extreme pacifism. If so, Franco cured him, for he was one of the most ardent supporters of the Spanish Republic in its glorious but unsuccessful struggle. It was natural that such a man should become, as he did, a member of the Communist Party.

His scientific work was remarkable as demonstrating the unity of practice and theory. Certainly no British physicist since Thomson, perhaps none since Newton, has combined such fundamental advances both on the technical and theoretical sides of his science. When his full biogrpahy can be written without hurting the

feelings of others yet alive, it will appear that his emotional life, without any detailed reference to his scientific or political work, might have furnished, and may yet furnish, the material for one of the world's great books. He was, in fact, an all-round man. We need such men to-day.

HOPKINS

SIR FREDERICK COWLAND HOPKINS, who died in May 1947, was the founder of modern biochemistry. But his work was relatively little known outside scientific circles, perhaps because few of his discoveries were of the kind that made headlines at the time, though they opened up new fields of research. What is more surprising, he only published about six papers of first-rate importance. Nevertheless, every biochemist to-day takes for granted a point of view which was revolutionary heresy when Hopkins first invented it and this point of view has been the major influence in biochemistry in the last 30 years.

Hopkins was a great analyst. He worked for some years in the laboratory of the Government analyst, and played a part, of which he seldom, if ever, talked, in securing the condemnation of a number of prisoners. The discovery which made his reputation was based on an analytical method. It had been long known that most proteins gave a colour reaction with acetic acid. One day hopkins was teaching a class of students how to get this and other reactions. One of the students, S.W. Cole, failed to get it. Some teachers would have told him to try again. Hopkins checked his work, and got no colour. He settled down to find out what was wrong, and discovered that the reaction was not due to acetic acid at all but to glyoxylic acid, which is a common impurity in laboratory acetic acid. When they used glyoxylic acid the reaction became much stronger, and he and Cole set out to discover what was the component in proteins which gave it. They finally isolated a substance called tryptophane which is present in some but not all proteins, and which he later showed to be a necessary constituent of any complete diet.

To prove this, he had to design a diet for rats on which they lost weight unless a tiny fraction of tryptophane was added, but grew

normally when the addition was made. It was not sufficient to give the rats proteins, fats and carbohydrates, as the books of fifty years ago stated. They needed something else, which Hopkins called accessory food factors, and obtained from milk. A worker who thought he had purified one of these factors gave it the name of vitamin, and this word caught on, in place of Hopkins's more accurate expression. But the two articles he wrote, in which he proved that rats need trytophane and a group of unidentified substances found in milk, have been models for all later work. It is noteworthy that his rats did not get particularly ill. But those kept on the complete diet grew so well that a loss of weight by the others was sufficient evidence that their diet lacked an essential constituent.

Hopkins never isolated any of the vitamins, though St. Gyorgy prepared one of them, ascorbic acid, in his laboratory; but he had, quite unintentionally, gone a long way to work out the structure of one of them. For he collected butterflies and matchboxes. From the wings of some butterflies he isolated a peculiar pigment called pterin, whose structure he partially worked out. Forty years later it was found to be a constituent of folic acid, one of the vitamins, and also of the substance which cures pernicious anaemia in men.

His other great discovery was his proof, with Fletcher, that lactic acid is formed in muscles when they contract. Since then scores of other such substances have been isolated, and indeed the chemistry of muscular contraction is fairly well understood. But this discovery was the first vindication of Hopkins's guiding principle, that it was possible to trace the whole set of transformations which a chemical substance underwent while passing through a living animal or plant.

Fifty years ago physiologists thought that food reaching living cells was somehow incorporated into living protoplasm, and that it was useless to apply ordinary chemical ideas to intermediary metabolism, which is the name given to the pattern of chemical changes

in the living cell. Hopkins believed that chemical principles could be so applied. His work on diet was guided by the idea that an animal needs certain compounds which it cannot make itself, and that a complete diet contains enough of each of them. Our rationing system is based on this simple idea.

In 1922 he became the first professor of biochemistry at Cambridge, and chose me as his second-in-command, perhaps because my work had been so very different from his own that he hoped that between us we should cover a pretty wide field. I think I disappointed him by deserting biochemistry, but I did at least learn some of his ways of thinking and apply them to genetics.

As a chief he was too kind and too modest. He would not plan other people's work or get rid of people who were wasting their time and his. On the contrary, he could be relied on to help his weaker pupils in their personal difficulties. I have never known a chief who was more universally loved by his subordinates. Fortunately some of them worked on the lines which he had laid down. In particular, Quastel and Stephenson found out a very great deal about the chemical processes going on in living bacteria, and laid many of the foundations for recent work on chemo-therapy.

He never produced a theory of the life process. The Laboratory published a humorous annual, *Brighter Biochemistry,* to which he contributed regularly. One of his articles, on biochemistry a hundred years hence, perhaps revealed what he really thought. The biochemists of the twenty-first century were applying higher mathematics to "psychoids" in the liver and other organs, while the physicists were mainly engaged in extremely accurate measurements of new properties of matter revealed by the biochemists. The framers of the current Soviet five-year research plan have a somewhat similar idea.

Rather late in his life his contemporaries recognised Hopkin's greatness, and within a few years of his becoming a professor he received the presidency of the Royal Society, the Nobel prize, the

Order of Merit, and other distinctions. He never took these honours quite seriously, and was at his best explaining to juniors in an after-dinner speech that the expectation of life of a Copley medallist of the Royal Society was only three years, so as he had received the medal promotions would soon occur. He was no politician, but an enthusiastic supporter and at one time president of the National Union (now the Association) of Scientific Workers.

We can do nothing more for Hopkins, but we can try to organise society so that scientific workers as socially modest and as intellectually bold as he get their chance in life earlier than he did, and can contribute as fully as possible to progress.

LEA

Last month (June, 1947) Dr. D. E. Lea, who had just been appointed Reader in Radio-Biology at Cambridge University, died as the result of a fall from a window. His death is not only a loss to pure science. It may conceivably entail your death or mine. For Dr. Lea was one of those workers engaged in investigating the action of radiations on living things who had refused to be entangled in the net of secrecy which spreads out in every direction round the atomic bomb. From what he said about such secrecy it is fairly clear that he would have refused to do secret work. So many discoveries which he might have made would have been available for the protection of the general public.

His book *The Action of Radiation on Living Organisms* is certainly the best summary available in any language of what happens when X-rays, gamma rays, or rapidly moving electrons, alpha particles, neutrons, and so on, penetrate living tissue. The effects of all these agents are very similar, because when a gamma ray or X-ray is stopped by an atom, a high-speed electron is shot out, and it is this which causes most of the damage before coming to rest.

The damage seems to be of two rather distinct kinds. In the first place cells which have been heavily irradiated cannot divide for some time, and often die when they do so. This is why X-rays are far more deadly to men or any other vertebrates than to adult insects. An insect is, in one respect at least, much more of a machine than is a man or a mouse. It is made of parts which are not replaced, and dies when they wear out. Its skin is hard, and no more is formed after its last moult or its emergence from a pupal case. Whereas our skins are constantly being replaced. So a dose of X-rays which will not harm an insect will cause serious skin burns in men, because the skin cells cannot divide to make a new skin as the old skin wears away. We are

also constantly replacing our blood corpuscles, by the division of cells in the bone marrow. So anaemia is another consequence of over-radiation. On the other hand cancer cells divide very frequently, so it is often possible to kill a cancer with X-rays while sparing the normal organs round it whose cells are not dividing.

X-rays and quickly moving particles have another effect to which Lea devoted more time. When a cell divides most parts of the new cell are made afresh. But some essential parts are copies of the corresponding parts of the old cells. If one of the uncopied parts is damaged this causes no permanent changes provided the cell survives at all. But if one of the copied parts is affected it is copied in its changed condition. And if the cell in question happens to be an ancestor of germ cells the change may be inherited for many generations. Such changes are called mutations, and though they are generally harmful, this is not always so. In a recent article I described useful changes produced in this way in crop plants in Sweden and in the Soviet Union.

Lea's most important work was a very careful comparison of the effects of different kinds of rays and quickly moving particles. He showed that if we are considering a single "target" in a cell, say a gene responsible for producing colouring matter in a fly's eye or hair on a barley-head, we can measure the area of the target from the chance of a "hit" by one kind of particle, and the volume from the chance of a hit by another kind. Thus he got two quite independent measurements of the size of a gene, which agreed very well. He applied the same method to measuring the size of viruses, such as the virus of cowpox which is used for vaccination. He went on to consider more complicated changes, such as rearrangement of the structure of chromosomes. I had the honour of helping him with some rather tricky mathematics which enabled him to get slightly more accurate results in this case.

I do not know what he would have done next. He might have investigated the possibilities of protection from these effects by chemical agents. This would be very important for workers on

artificial radioactivity and atomic fission who receive accidental injuries, and perhaps even in defending populations against atomic bombs. For example, tadpoles can be protected from the effects of X-rays by keeping them in very cold water after a heavy dose, so that their cells have a chance to recover before they divide. You cannot cool a man down much without killing him. But you can slow down cell division with sulphanilamide derivatives, and this might conceivably save his life.

Any experiments to test such a possibility would have to be extremely critical; and Lea was nothing if not critical, at least as critical of his own work as of other people's. In fact, he made his most fundamental discoveries because in some of his earlier work different kinds of treatment had given results much more different than were expected on the basis of the theory on which he was working. He pointed out the contradiction, and in the course of explaining it he did a number of most important experiments, and showed how one kind of treatment measures the area of the target, and another its volume.

Most of the other British scientists on this subject are more or less gagged by "security" regulations. They may merely have been asked for advice on the protection of workers with radioactive substances, but in giving such advice they have learned facts which are secret. Now these questions will become more and more important. So will the question of the protection of the public from the waste products of factories or laboratories such as that at Harwell. Personally I believe that up till now the public is in no danger.

But I have not got Lea's knowledge of the scientific side of this work; and those who have a comparable knowledge (I do not think anyone has as much) are muzzled. The question will certainly come up before the public in the next few years. And no one will be able to advise them as Dr. Lea could have done. That is why his death is a serious matter for you and me.

JEANS

Sir JAMES JEANS was very competent mathematician who applied his talents mainly to the study of gases. He worked on the theory of gases at ordinary temperatures and pressures, introducing various refinements of the simple theory which treats the gas molecules as if they were perfectly smooth elastic balls, and which gives a good approximation to the observed facts.

Even more important was his work on gases at very high and low temperatures and pressures. He showed that the solar system could not have originated, as Laplace thought, from condensations in a spinning disc-shaped mass of gas, each condensation attracting the gas in its neighbourhood and becoming a planet. However the nebular hypothesis has been revived by Weiszäcker, with additional postulates which at least partially meet Jeans' criticisms. His book *Problems of Cosmogony and Steller Dynamics* was a landmark in the history of astronomy. It was however based on physical theories which are now known not to be quite exact. Nevertheless, no subsequent worker can conceivably neglect it.

For some time Jeans had told his friends that at the age of 55 he proposed to abandon pure science and devote himself mainly to popularisation. He did so with the greatest success. But future generations will remember him for his earlier work.

He died in 1946, and his last book, *The Growth of Physical Science* * has just been published. This is a history of physics and of some branches of mathematics from the earliest times and is very well worth reading. There are a few slight mistakes, particularly in the index, which the author would probably have corrected had he

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lived, but they are quite irrelevant to his main argument. To me, the most interesting parts of the book are the quotations from Copernicus, Newton, and other great men. What they actually wrote was often very different from the summaries of their views which are usually given. In particular Newton did not plump for a corpuscular theory of light, as is often stated.

Unfortunately, the last chapter, which deals with modern developments, is hardly up to the standard of its predecessors. One reason for this is that Jeans tells us nothing of the history of the theory of probability, but suddenly introduces this notion in connexion with quantum mechanics. Now the theory of probability is something highly practical. It arose from a consideration of gambling and insurance, and has been applied in almost all branches of science. On page 335 Jeans equates probability with knowledge. This idealistic formulation is only sometimes true. If I say there is a probability of one in fifty-two that the top card in a well shuffled pack is the ace of spades, this is equivalent to stating that I know nothing about which card is there. But if I talk of the probability of future events we can only equate it with partial knowledge if we think that all future events are absolutely determined already. If we believe that human beings can make real choices, then the probability that I shall get drunk tomorrow is something quite different from the probability that the top card is the ace of spades.

In fact, as is so often the case, Jeans' idealistic account of probability is only a manifestation of mechanistic thinking. If you insist on treating the universe as a machine, you will have to bring in supernatural agencies to explain the facts of ordinary experience as well as those of advanced physics. His account of modern theories of the universe is far from satisfactory. Many questions, including that of the alleged expansion of the universe, are certainly far more open than a reader of his book might suppose.

For an up-to-date discussion of this question and of theories

of the universe in general, I cordially recommend Paul Laberenne's *L'Origine des Mondes.* *For one thing he devotes a whole chapter to Jeans' work, which Jeans himself, with rather undue modesty, dismisses in a paragraph. But he also describes the work of Tolman in America, of Fessenkoff in the Soviet Union, of Banerji and Sen in India, and of Milne in England, to mention no others, which lead to points of view decidedly different from those of Jeans.

The book is written from a Marxist angle, and is only one of a number of excellent books on science which are being written by French Marxists. My only criticism of it is as follows. The author takes such care to avoid mathematical arguments which his readers might not be able to follow, that they may not realise the great knowledge of mathematics which is needed before one can criticize an astronomical theory, let alone produce one. I constantly get letters containing astronomical theories which are either so vague that they cannot be tested at all, or alternatively which would require years of work to see whether they agreed well enough with the known facts to be worthy of further examination.

However, much we may criticize such men as Jeans and Eddington, they were first-rate mathematicians, and their theories were worked out in great details. Laberenne is a professional mathematician, and his criticisms are based on a very considerable knowledge. In fact they go deeper than a reader might think at first sight. He also sees clearly the social background of the views held by different astronomers. Jeans, in his second chapter, sees clearly enough why slavery led to a contempt for practice which sterilized Greek science. In his sixth chapter he writes of the origin of the Royal Society, quoting Boyle's description of it as "our new philosophical college which values no knowledge but as it has a tendency to use". Unfortunately he has nothing to say about the relation between science and society in our own time.

*The origin of worlds, Editiors Hier ed Aujourd'hui Paris.

Lamberenne fills this gap. We see clearly how, for example, a French catholic writer, M.de Launay in *L'Eglise et la Science,* joined with the Nazis in attacking relativity because Einstein was a Jew, oblivious of the fact that the Jesuit Lemaltre had made an important contribution to it. But as Lemaltre had the bad taste to agree with a Soviet mathematician, Friedmann, he stood condemned. He explains the reasons which made so many astronomers accept rather uncritically the arguments suggesting that planets were very rare, so that it was unlikely that there were intelligent beings on other stars. The evidence of the last three years suggests that planets are rather common.

In fact, we cannot study even astronomy without remembering that astronomers are human, and therefore, part of society. Laberenne never forgets this fact, and that is one reason why I hope that his book may be translated into English.

G.H. HARDY

Professor G.H. Hardy, who died last month (November, 1947), was probably the greatest British mathematician of his generation, and one of the greatest in the world. Like many great men, he held views and did things which do not easily go together in the lives of ordinary men.

He was a very pure mathematician. Much of his work was on the theory of numbers. For example he and his colleagues tackled the problem of the number of partitions of a given number. Consider the number three. You can express it as 3 as 2+1, or as 1+ 1+1, that is to say split it up in three ways. Four can be written as 4, 3+1, 2+2, 2+1+1, or 1+1+1+1, that is to say in five ways, and five in seven ways. But how can we find an expression for the number of partitions of any number? He finally arrived at the formula, which is fairly complicated. He then tackled similar problems, such as the number of ways in which a number can be broken up into a sum of a given number of squares, cubes and so on.

If anyone told him that such work was completely useless, he was the first to agree. He boasted that his mathematics had never helped to kill a single man, and stated that mathematics were something like cricket, worth doing for its own sake. He was an intense admirer of cricket and cricketers. He would admit that various mathematicians had been in the first class. But he put half a dozen or so of them in what he called the Hobbs class, after the great Surrey cricketer. In actual fact his boast was untrue. To take one single example, there is a function called Riemann's Zeta function, which was devised, and its properties investigated, to find an expression for the number of prime numbers less than a given number. Hardy loved it. But it has been used in the theory of

pyrometry, that is to say the investigation of the temperature of furnaces. And blast furnaces play a very important part in modern war.

Even cricket has its social functions. For example in spite of the strong resentment aroused by Larwood's bowling, it has certainly cemented friendship between Britain and Australia; and the prowess of Indian and West Indian cricketers has made some Englishmen who would not otherwise have done so respect members of darker coloured races. Hardy's pure mathematics had a social function of this kind. In 1913, an unknown Indian clerk, Ramanujan, sent him a letter containing about a hundred mathematical theorems. Hardy got him over to England, and he became the first Indian fellow of Trinity College, Cambridge, and later of the Royal Society.

Unfortunately he got tuberculosis. As he lay dying of it, Hardy visited him. He asked Hardy for the number of his taxicab. Hardy replied "1729, not a particularly interesting number." "What," replied Ramanujan "don't you realise that it is the smallest number which can be expressed in two different ways as the sum of two cubes?" (10^3+9^3 or 12^3+1^3). Or so the story goes. Hardy is alleged to have said that Ramanujan was on terms of personal friendship with every number less than 10,000.

In spite of this attitude to this profession, which many readers of this article will regard as futile and reactionary, Hardy was a staunch opponent of what he regarded as injustice and superstition, a socialist and a trade unionist. I remember him making a recruiting speech for the National Union of Scientific Workers, which as of course a Trade Union up to 1927, and as the Association of Scientific Workers, is one again. He argued that science and mathematics were worth doing for their own sake. But he went on to say that although our jobs were very different from a coalminer's, we were much closer to coal miners than to capitalists. At least we and the miners were both skilled workers, not exploiters of other people's work, and if there was going to be a line-up he was with the miners.

The idea of art for art's sake or mathematics for mathematic's sake is an incomplete idea. But it is very much better than the idea of art for money's sake, or mathematics for engineering's sake, no matter how the engineering is to be used. If you really believe in art for art's sake you will soon want to change things so that everyone who wants can get a chance to practise art and to enjoy it. That means working for a society where everyone has the necessary leisure and means, in fact for socialism. That was as far as G.H. Hardy got.

The next stage is reached when the artist realises that his art can become a weapon for socialism, and be all the better for it. Men like William Morris, Alan Bush and, in his early plays, Bernard Shaw, got to this stage. It is certainly harder for a mathematician to do so, because mathematics only appeal to the emotions of a few people, and can only be used directly for socialism after socialism has been won.

Though I disagree with Hardy's attitude I regard it as one-sided rather than wholly wrong. It is right that every skilled worker should take pride in his or her work, particularly when it is not done to increase someone else's profits. Hardy spent his life devising intellectual tools, which he tried out on the easiest material to hand, namely "pure" numbers. Other people have used these tools for the study of mechanical systems such as telephones, and living ones, such as brains. To take an example from my own work, I have just used part of the theory of the partitions of numbers to analyse family records to see whether, on an average, certain diseases occur more often among the Later born members of a family than the earlier ones.

I happen to be one of those who find an intense aesthetic pleasure in mathematics quite apart from its applications. I quite realise that this is not enough. But I also realise that those who enjoy it most are likely to do it best. So I do not feel that Hrdy's attitude was wholly wrong, and I mourn a man whom I not only liked personally, but whose writings gave me some of the emotions which other derive from classical music.

EINSTEIN

Einstein's seventieth birthday was on 14th march (1949). He is generally recognised as the greatest living mathematical physicist. Of course, younger men are now making greater contributions to that subject than he has done in the last ten years, but no one has yet equalled his earlier work. He is best known for his work on relativity. But if he had never written a line on that subject, he would still be regarded as a scientist of the first rank.

The quantum theory was founded by Planck, but it was Einstein who made the simplest and probably the most universally valid statement about it, namely that when matter emits or absorbs light, the energy is transformed in single units. And the size of the unit is proportional to the frequency of the light. The energy of blue light is given out in bigger packets than that of red light, and that of red light in bigger packets than that of infra-red radiation, which we cannot see, but can feel as heat. That is why when we heat a metal it gives out red light before it gives out white. At a red heat some atoms have enough energy to produce red light, hardly any have enough to produce green or blue, which must be added to the red to make white.

However, his work on relativity was even more important. Let us try to explain it. Our "common sense" view is that everything has a definite shape and size, that an event happens at the same time as a class of other events, and so on. What is more some people seem to think that any denial of this view is idealism.

Let us take a simple example to show that our common sense view won't work. I drop a parcel in a steadily moving train. To me it seems to fall in a straight line, or nearly so. To you, standing on the platform as the train goes past, it seems to move in a curve called

a parabola, the descent becoming steeper and steeper as the time goes on. If the earth were fixed, you would perhaps be right. But as the earth is moving too, there is little to choose between the two versions.

Does that mean that the parcel has no real track, and is only something in our minds? Not a bit, says Einstein; you can give an account of the parcel's movement which will be the same for all observers. So it is probably a considerable step nearer to reality than either my account or yours. But to give such an account we have to revise our accounts of space and time. There is an interval between any two events, and there are three sorts of intervals.

The first sort of interval can be interpreted by me as entirely one of time, that is to say I may think two events happened at the same place and different times. But if you are moving relative to me you will say they happened at different places and different times.

The second sort of interval can be interpreted as entirely one of space. That is to say I think two events happened at the same time in different places. But to you they may seem to have happened at different places and also at different times.

Common sense, rather reluctantly, recognises the first kind of relation between events. We all agree that if London is spinning round the earth's axis, two events in the same room at an hour's interval can be said to be hundreds of miles apart. But it took Einstein to see that "at the same time" was just as relative to the observer as "in the same place". There is a third kind of interval between events which all observers will agree are separated both in space and in time.

Of course, if he had stopped there his work would merely have been negative. But he was able to describe a framework of space-time which was the same for all observers, though they would interpret it a little differently. This at once cleared up a lot of contradictions in physics. People had tried to measure how fast the

earth was moving through space by measuring the speed of light at different times of year, and had found no difference. If Einstein is right, they could not hope to find one, because space has no being of its own apart from matter.

I think most physicists are agreed that Einstein's theory works very exactly so long as the two observers are in uniform motion relative to one another, like a man on a platform and a man in a steadily moving train. But things are not so simple when the speed of one relative to the other is changing, for example when the train is accelerating or slowing down. Everyone knows that acceleration generates forces, for example an accelerating or decelerating trains seems to slope even when the track is flat. Einstein said that the man in the moving train who thinks its floor is off the straight has a perfect right to his opinion, and on this basis he predicted that gravitation and acceleration would have similar effects.

In particular light should be bent by a very strong gravitational field. This prediction was verified by Eddington during an eclipse of the sun in 1919. What is more, it was bent to the extent which Einstein had predicted. More and more other predictions came off. Einstein said that a body in motion relative to a balance was heavier than the same body at rest. So is a body with potential energy. Your watch weighs more than wound up than when run down. The amount of energy in a watch is much too small to weigh by methods at present available. But the amount of energy in a large number of radioactive atoms is enough to make them weigh distinctly more than the products formed when they split up. And this energy has been weighted.

However, the general theory of relativity, that is to say the theory applied to systems whose parts are not in uniform motion relative to one another, is not complete. When one attempts to apply it to events which are very far apart in space or time it yields results which are probably incorrect. There is nothing surprising in this. One only approaches the truth by steps. Einstein made a very big

step, but he is much too good a physicist to think that he has made the last one.

Of course, Einstein's theories can be interpreted idealistically and he has sometimes done so himself, though never completely. There is a measure of truth in the idealistic interpretation. The idealists say that what we call the material world only exists in our minds. A follower of Einstein would say something like this. Events, such as human births and deaths, chemical changes or solar eclipses, are real enough. But the framework of space and time, into which we try to fit them, is partly our own construction. There is a real set of relations between events. But different people interpret it in different ways. I say the parcel fell in a straight line, you say it fell in a curve. Each of us was giving a one-sided account of a track in space-time.

Reality is more complicated than we think. But that does not mean that things aren't real. On the contrary one might say they are more real than any isolated observer could have imagined. Only by the social act of comparing the experiences of different observers can we make the important step towards truth which Einstein was the first to make.

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